Georgia Nuclear Laboratories

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ER-7510

COMPONENTS IRRADIATION TEST NO. 5
HPA-1002 AND 1N1616 DIODES
S2N1724 AND 2N2222 TRANSISTORS
2N511 FLIP FLOP BISTABLE NETWORK
SN522 OPERATIONAL AMPLIFIER

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Prepared For:

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FOREWORD

This report is submitted to the Astrionics Laboratory of the George C. Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Alabama, in accordance with the requirements of Task Order No ASTR-LGC-14 of Contract No. NAS 8-5332. The report is one of a series describing radiation effects on various electronic components. This particular report concerns diodes, transistors, integrated circuit flip flops and operational amplifiers. The tests were performed by the Georgia Nuclear Laboratories, Lockheed-Georgia Company.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

LIST OF TABLES AND FIGURES
(Continued)

LIST OF TABLES AND FIGURES
(Continued)

LIST OF TABLES AND FIGURES
(Continued)

1.0 SUMMARY

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Two types of diodes, two types of transistors and two types of microelectrionic circuits (an amplifier and a flip flop) were subjected to a radiation environment at a controlled temperature of $37 \pm 0.5^{\circ}$ C. Irradiation was continued until the specimens had accumulated an average integrated flux of 5.4×10^{14} n/cm^2 plus an average gamma dose of 7.5×10^{6} r. During the irradiation measurements were made to define V_F and I_R for the diodes; h_{FE}, I_{CBO}, and V_{BE} for the transistors; and output voltages of the amplifiers and flip flops.

Test results indicated:

(1) For the type HPA-1002 diode - V_F was decreased slightly by the radiation; I_R of some specimens was increased beyond the failure point, while I_R of most specimens remained within limits throughout the test.

(2) For the type 1N1616 diode - all specimens failed due to 100% increase in V_F; I_R was increased by radiation but not beyond specification limits prior to failure.

(3) For the type S2N1724 transistor - all specimens failed due to 50% reduction in h_{FE}; I_{CBO} increased slightly prior to failure; V_{BE} with I_C constant increased, while V_{BE} with I_B constant decreased slightly; input impedance increased during the first part of the test, then decreased to a value lower than pre-test value at point of failure.

(4) For the type 2N2222 transistor - all specimens failed due to 50% reduction in h_{FE}; I_{CBO} showed a large increase; V_{BE} with I_C constant remained essentially constant; V_{BE} with I_B constant decreased slightly; input impedance showed a marked increase.

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(5) For the type SN522 operational amplifier - all specimens failed due to 50% decrease in output voltage.

(6) For the type SN5II flip flop - all specimens failed due to output voltage variations beyond specified limits.

Ranges of radiation exposure over which failures occurred were:

Type	Failure Range
HPA-1002	2×10^{8} to $>5.4 \times 10^{14}$ n/cm^2
1N1616	1.0×10^{13} to 1.6×10^{13} n/cm^2
S2N1724	3.8×10^{11} to 8.0×10^{11} n/cm^2
2N2222	Not determined
SN511	6.1×10^{12} to 1.6×10^{14} n/cm^2
SN522	3.3×10^{11} to 1.3×10^{13} n/cm^2

2.0 INTRODUCTION

The experiment described in this report is the fifth irradiation of electronic components and is the ninth in a series of radiation effects tests on electronic equipment, circuits, and components contemplated for use on a nuclear space vehicle. Since the use of equipment on this vehicle is contingent upon its ability to withstand the nuclear environment, the Astrionics Laboratory of the Marshall Space Flight Center has undertaken to assure that Government furnished or specified equipment will survive this environment. The equipment is to be subjected to the expected nuclear environment as simulated at the Georgia Nuclear Laboratories. Measurements made on the equipment during the irradiation will describe its radiation tolerance.

The subjects of this test are the types HPA-1002 and 1N1616 diodes, the types S2N1724 and 2N2222 transistors, the type SN511 flip flop bistable network, and the SN522 operational amplifier.

3.0 TEST PROCEDURE

The test specimens were supplied by the Astrionics Laboratory of the Marshall Space Flight Center. They were exposed to a nominal gamma dose of 5.5×10^5 r behind a neutron attenuator shield. The shield was then removed and the test was resumed until a nominal integrated neutron flux of 5.4×10^{14} n/cm^2 was accumulated. During the test all specimens were mounted in a controlled temperature chamber held at $37^\circ C \pm 0.5^\circ C$. Before, during and after the test measurements necessary to determine the parameters listed in Table 1 were made. Measurements were also made during the test to define the nuclear and temperature environments.

3.1 TEST SPECIMENS

The specimens tested are listed in Table 1. All specimens were mounted by the Astrionics Laboratory. The specimens were new units and had only been subjected to receiving inspection. Manufacturer's specifications for the specimens are shown in Table 2. Instrumentation circuity and mounting hardware were provided by GNL.

3.1.1 Specimen Mounting

The specimen boards were mounted vertically on the test fixture to equalize, as much as possible, the radiation flux distribution over the test specimens. Figures 1 and 2 show the relative positions of the specimens as mounted. The test fixture was placed in a controlled temperature chamber adjacent to the reactor.

3.2 TEST SPECIMEN MEASUREMENTS

A complete set of data was taken at $37^\circ C$ prior to reactor startup to establish baseline data for the test. During the irradiation, measurements were made at all reactor power settings. Measurements were also made: (a) during the 45-minute reactor shutdown for removal of the LiH shield; (b) immediately after reactor shutdown upon completion of the irradiation; and (c) approximately 12 hours after completion of the irradiation on non-failed specimens. All measurements were made with the test fixture in place at the reactor facility.

3.3 INSTRUMENTATION

3.3.1 Diode Measurement Circuits

The circuits of Figures 3 and 4 were used to perform the diode measurements with the GNL digital voltmeter data logging system. The cathodes of all the diodes were commoned and the anodes were commutated into the test circuits. Before the irradiation, short circuits were established across each diode specimen and measurements were taken at the programmed current to establish the voltage drop in the 300' cables from the measurement circuits to the test specimens. These voltage drops were subtracted during data reduction from the forward voltage drop measurements recorded by the digital voltmeter system. The maximum system sensitivity for the reverse current measurements was in the order of 10^{-9} amps.

3.3.2 Transistor Measurement Circuits

The transistor measurement circuits are shown in Figures 5, 6 and 7. The emitter of each type of transistor test specimen was commoned and the base and collector were commutated into the various test circuits. The system sensitivity of the I_{CBO} measurement circuit, Figure 5, was in the order of 10^{-6} amps.

Figure 6 is the h_{FE} measurement circuit. The feedback loop, including the amplifier "A", establishes the base current necessary to provide the collector currents tabulated in Table 1. The base current is measured by the digital voltmeter system. h_{FE} is calculated from these measurements. A V_{BE} measurement was also included in this test circuit, wherein the digital voltmeter system was allowed to monitor the voltage existing between the base and emitter of each test specimen.

A second type of V_{BE} measurement circuit was included in the test. Measurements of V_{BE} were performed in a circuit which was designed to provide a constant base current (Figure 7). V_{BE} corresponding to each of two base currents was measured. The collector to emitter voltage was held constant for all measurements.

3.3.3 Amplifier, SN522 Measurement Circuit

The integrated circuit amplifiers were provided with the bias voltages noted in Figure 8. A 2 mv peak to peak 1 kc input signal was provided alternately to the normal and inverted inputs. Since the amplifier input voltage had to be measured in the operations area 300 cable feet from the test specimen, a 10 ohm resistor was shunted across each amplifier to preclude loading of the driving source by the long cables. This resistor also eliminated oscillations in the amplifier systems. All terminals of each amplifier were switched in and out of the measurement circuit.

3.3.4 Flip Flop, SN 511 Measurement Circuit

The integrated circuit flip flops were provided with the voltage shown in Figure 9. Measurements of each side of the flip flop, both loaded and not loaded, were performed throughout the irradiation. The output terminals were shorted to ground to effect switching of the circuits. Load switching was also included as shown in Figure 9. All circuits of these units were switched in and out of the measurement circuit.

3.4 TEST ENVIRONMENT

3.4.1 Pressure

The test was conducted at atmospheric pressure.

3.4.2 Temperature

The specimens were irradiated in a temperature controlled environment of $37^{\circ}C \pm 0.5^{\circ}C$, except that near the end of the test the temperature rose gradually to

$41^{\circ}C$ due to a combination of gamma heating and high ambient temperature. Figure 10 is a graph of the environmental temperature versus integrated neutron flux.

3.4.3 Nuclear

All test specimens were subjected to a simulated nuclear vehicle environment. The irradiation was performed in two phases. The first phase was conducted with a lithium hydride shield interposed between the test specimens and the reactor. The second phase was conducted with no shielding. The neutron/gamma ratio behind the shield was about 8×10^5 nvt/r, as compared to about 10^8 nvt/r without the shield. During the irradiation both neutron and gamma radiations were monitored and recorded.* Isoline radiation flux plots were made for the test panel to aid in data reduction.

* A more detailed description of the GNL Nuclear Measurement System is contained in previous reports; viz. Components Irradiation Test No. 1, ER-6785, Georgia Nuclear Laboratories, Dawsonville, Georgia.

4.0 METHOD OF DATA ANALYSIS

The GNL Data Logging System recorded the parameter measurements except for those taken on the SN511 Flip Flop network which were manually recorded. All data were transferred to IBM cards which were then programmed into an IBM 7094 computer to yield the parameters shown in the figures which depict the test results. Since data measurements could not be made simultaneously on all specimens, and since the flux rate was not uniform over the entire test panel, it was necessary to program the data from each specimen separately to provide a plot of the measurement under consideration versus radiation exposure. Parameter values were than calculated from the plot at selected radiation exposure levels and processed for group median values and envelope limits.

The mean parameter value where shown for a data group was computed by adding the individual specimen parameter values and dividing the sum by the number of specimens. Normalization of h_{FE} was accomplished by dividing each h_{FE} value by its corresponding pre-irradiation value.

The median parameter value for a data group (that value which divides a distribution so that an equal number of items is on either side of it) was determined graphically from a plot of the individual specimen parameter values on arithmetic probability paper. The limits of the 68% envelopes were determined by picking off those values within which were contained 34% of the specimens next above the group median value and 34% of the specimens next below the group median value. The limits of the 95% envelope were found in a similar fashion.

For those groups which contained less than 10 specimens, the parameter values for each specimen have been shown rather than the 68% and 95% envelopes.

Radiation environmental data shown on the figures' abscissae were obtained by integrating, with respect to time, the gamma dose rates and neutron fluxes.

Figures 16 and 19 were prepared after the procedure described by Mr. Frank W. Poblenz in a paper entitled, "Analysis of Transistor Failure in a Nuclear Environment," which appeared in Volume NS-10, Number 1, January 1963, of the IEEE Transactions on Nuclear Science. This type of presentation enables the circuit designer to predict the radiation level at which any given percentage of the particular component will equal or exceed the failure criteria.

Copies of the reduced data from which the graphs were prepared are on file in the Astrionics Laboratory of the George C. Marshall Space Flight Center, NASA, Huntsville, Alabama, and in the Georgia Nuclear Laboratories, Lockheed-Georgia Company, Dawsonville, Georgia.

5.0 TEST DATA AND DISCUSSION OF RESULTS

The test data have been presented herein in graphical form. The radiation exposure is, in all cases, a combination of neutrons and gammas. The abscissa scale on each of the graphs is accumulated neutrons/cm^2 greater than 0.5 MeV. However, the coincident accumulated gamma dose (r) is also indicated at those points where changes in the reactor power rate occurred. It is important to remember that the total radiation exposure consists of both neutrons and gamma, and that each may contribute, in varying degrees, to the degradation of a component's parameter.

5.1 TYPE HPA-1002 DIODE

Usable data were obtained from 15 specimens during the irradiation. Figures 11 and 12 show the behavior of the V_F parameter for two values of I_F. Apparently, radiation had little effect on this parameter other than to cause a slight decrease in the V_F during the first part of the test. Post-test readings showed partial recovery toward initial values.

Figure 13 shows I_R versus integrated neutron flux. A portion of the measured increase is undoubtedly due to radiation rate effects in the instrumentation cables. An attempt will be made in future tests to determine the exact contribution of the cables. Of the 15 specimens one had a pre-irradiation I_R of .31 μa. This specimen remained consistently higher than the median throughout the test and accounts for the large width of the 95% envelope. Three of the specimens developed I_R values in excess of 2000 μa during the test. The points of these failures are indicated in Figure 13 by the dotted lines exiting from the "median" line. Thus only 12 specimens survived the test, and their median I_R was on the order of 0.3 μa at 5×10^{14} n/cm^2. During the post test measurements on the following day, two of the surviving 12 had I_R values in excess of 300 μa. The other 10 specimens had a median I_R value of about 0.1 μa.

5.2 TYPE 1N1616 DIODE

All eleven operative specimens failed furing the test due to a 100% increase in V_F. Figures 14 and 15 show the V_F parameter for two values of I_F. Figure 16 shows the failure patterns for the two I_F values. There appears to be no significant difference in the rate of increase in V_F nor in the pattern of failure. Figure 17 shows the I_R behavior during the test. The median I_R for the group exceeded the manufacturer's specification of 10 μa at about the radiation level where V_F doubled (1.4×10^{13} n/cm^2). Radiation rate effects in the instrumentation cables undoubtedly contributed to the increase in the measured I_R values.

5.3 TYPE S2N1724 TRANSISTOR

Thirteen specimens were operating satisfactorily at the beginning of the test, but usable h_{FE} data were obtained from only 10 specimens. Figure 18 shows the decrease in h_{FE} due to radiation exposure. All 10 specimens failed (50% decrease in h_{FE}) during the test with the first failure occurring at 3.8×10^{11} n/cm^2 and the last at 8.0×10^{11} n/cm^2. Figure 19 shows the pattern of failure. Initial values of h_{FE} and order of failure are tabulated below:

h_{FE_o}	Order of Failure
40.82	10
41.15	7
41.45	9
49.19	6
60.61	2
64.01	3
65.66	8
65.76	4
70.22	5
70.61	1

There appears to be a slight correlation between high values of h_{FE_o} and early failure.

Figure 20 shows I_{CBO} versus radiation exposure. All values were well below the manufacturer's specification of 10 ma up to 2×10^{12} n/cm^2. These measurements were discontinued after failure (50% decrease in h_{FE}) of all specimens.

Figures 21, 22 and 23 show the behavior of the V_{BE} parameter under the indicated conditions of I_B and I_C. For greater ease in making comparisons, the medians of these three figures are shown in Figure 24.

Figure 25 shows the variations in input impedance versus integrated neutron flux . The values were calculated by determining the slope of the dc input characteristics between two base currents; i.e., by subtracting V_{BE} (I_C = .75 a) from V_{BE} (I_C = 1a) and dividing the remainder by the difference between the I_B values in the two applicable measurement circuits.

5.4 TYPE 2N2222 TRANSISTOR

Fourteen specimens were operative at the beginning of the test. The absolute accuracy of the h_{FE} and I_{CBO} data obtained from individual specimens of this group is doubtful because other considerations necessitated the use of instrumentation with less than the desired sensitivity for these measurements. Therefore, in Figure 26 only the mean curve of the normalized h_{FE} has been shown and no attempt has been made to delineate the 68% and 95% envelopes. For the same reason, no attempt has been made to determine the range of radiation exposure over which failures occurred.

In Figure 27, the 68% and 95% envelopes for I_{CBO} values have been shown. However, any I_{CBO} values below 1 μa are questionable because of the limited instrumentation sensitivity. The values shown have not been corrected for radiation rate effects in the instrumentation cables.

The V_{BE} data shown in Figures 28 through 31 show practically no change with I_C

constant at 10 ma and a slight decrease with I_B constant.

The change in input impedance was computed by the method explained in paragraph 5.3 using the group mean values of V_{BE} (I_C = 10 ma) and V_{BE} (I_C = 20 ma). The results, shown in Figure 32, indicate an increase in input impedance with radiation exposure.

5.5 THE TYPE SN522 OPERATIONAL AMPLIFIER

Data were obtained from eight specimens during the test. Figures 33 and 34 show the measured output voltages of each specimen plotted against integrated neutron flux. Figure 35 shows the mean output voltages versus integrated neutron flux. Pre-test output voltage values and order of faliure for the two measured outputs are tabulated below:

Pin 9		Pin 10	
Pre-Test Output	Order of Failure	Pre-Test Output	Order of Failure
.4309	8	.4399	8
.5101	6	.4499	7
.5781	7	.7300	4
.9100	5	.8300	3
.9301	2	.9000	5
.9641	4	1.0200	6
1.080	3	1.0600	2
1.179	1	1.0700	1

There is good correlation between high initial output values and early failure. However, it should be noted in the figures that the specimens with high initial outputs generally had relatively higher absolute outputs at any given radiation exposure level. If the failure criteria had been a decrease to a given absolute output voltage, rather than a 50% decrease in initial output, then the specimens with the higher initial outputs would have been among the last to fail.

The following tabulation shows that failures (50% reduction in initial output) ranged from 3.3×10^{11} to 1.3×10^{13} n/cm^2:

Specimen No.	Integrated Neutron Flux (n/cm^2) When Output Decreased 50% Pin 9 Output	Pin 10 Output
9	8.6×10^{11}	*8×10^{11}
10	5.3×10^{11}	*4.4×10^{11}
11	*4.2×10^{11}	5.5×10^{11}
12	6.5×10^{12}	*6.5×10^{11}
13	*3.3×10^{11}	3.9×10^{11}
14	2.5×10^{13}	*1.3×10^{13}
15	*2.1×10^{12}	3.4×10^{12}
16	1.4×10^{12}	*7×10^{11}

*Earliest Failure Point

5.6 THE TYPE SN511 FLIP FLOP BISTABLE NETWORK

Seven of the eight specimens were operating satisfactorily at the start of the irradiation. The output voltage data for all seven specimens under the "on"-"off," "load"-"no load," conditions are shown in Figures 36 through 43. Mean output voltages for the various configurations are shown in Figures 44 and 45. Considerable annealing is indicated during the zero radiation, 45 minute shield removal period.

Failure of this type network was defined as "OFF" position output voltage less than 3.8 VDC or "ON" position output voltage greater than .30 VDC. All failures, however, were evidenced by inability of the unit to switch operational states rather than a gradual deterioration of the output voltage levels.

Specimens 1, 4 and 7 showed greater radiation tolerance in all modes of operation than the other five specimens.

As can be seen from the following summation, failures ranged from 6.1×10^{12} n/cm^2 to 1.6×10^{14} n/cm^2.

Integrated Neutron Flux (n/cm^2) When Off Output Voltage $\leq$ 3.80				
Specimen	Pin 8		Pin 9	
	Load	No Load	Load	No Load
4	1.3×10^{14}	-	$*1.2 \times 10^{14}$	-
3	$*1.3 \times 10^{13}$	6.6×10^{13}	$*1.3 \times 10^{13}$	8.5×10^{13}
2	4.5×10^{13}	7.5×10^{13}	6.0×10^{13}	9.5×10^{13}
1	$*1.6 \times 10^{14}$	-	1.7×10^{14}	-
8	$*6.1 \times 10^{12}$	6.0×10^{13}	1.8×10^{12}	8.0×10^{13}
7	1.5×10^{14}	1.6×10^{14}	$*8.0 \times 10^{13}$	-
6	$*2.9 \times 10^{13}$	8.1×10^{13}	3.7×10^{13}	9.0×10^{13}

Integrated Neutron Flux (n/cm^2) When On Output Voltage $\geq$ .30				
Specimen	Pin 8		Pin 9	
	Load	No Load	Load	No Load
4	-	-	-	-
3	8.5×10^{13}	4.8×10^{13}	8.0×10^{13}	7.2×10^{13}
2	9.0×10^{13}	$*3.8 \times 10^{13}$	7.0×10^{13}	9.0×10^{13}
1	-	-	-	-
8	6.0×10^{13}	2.9×10^{13}	6.5×10^{13}	6.3×10^{13}
7	-	2.5×10^{14}	-	1.7×10^{14}
6	5.0×10^{13}	3.3×10^{13}	9.0×10^{13}	8.0×10^{13}

*Earliest Failure Point

TABLE 1 - TEST SPECIMENS AND TEST CONDITIONS				
Board Number	Description	Number Tested	Test Conditions	Parameters
2	Diode HPA-1002 Hewlett-Packard	40	I_F 150 ma, 300 ma V_R 30 V	V_F I_R
4	Diode 1N1616 General Electric	15	I_F 1 amp, 2 amps V_R 600 VDC	V_F I_R
5	Flip Flop - Type SN511 Diffused Si Bistable Network Texas Instruments	8	V_3 6V, No Load	V_8 OFF, V_8 ON V_9 OFF V_9 ON
			V_3 6V, Load - 1.5 K in series with 1N914	V_8 OFF V_8 ON V_9 OFF V_9 ON
	Amplifier - Type SN522 Microelectronic Operational Amplifier	8	+ + V_{CC} 10 ± .2VDC + V_{CC} = 6V ± .2VDC - V_{CC} -9 ± .2 VDC V_{in} Pin 9 with Pin 10 grounded V_{in} 2 mv peak to peak 1Kcs	Output Voltage V_2
			Bias supplies same V_{in} Pin 10 with Pin 9 grounded. V_{in} 2 mv peak to peak, 1Kcs	Output Voltage V_2
6	Transistor - S2N1724 NPN, Si, High Power Texas Instruments	15	V_{CE} 15 VDC, I_C 1 amp V_{CB} 100 VDC, I_E 0 V_{CE} 20 VDC, I_B = 20 ma V_{CE} 20 VDC, I_B 30 ma	h_{FE}, V_{BE} I_{CBO} V_{BE} V_{BE}
7	Transistor - 2N2222 NPN, Si, Low Power Motorola	20	V_{CE} 10 VDC, I_C 10 ma V_{CB} 50 VDC, I_E 0 V_{CE} 10 VDC, I_B 70 μa V_{CE} 10 VDC, I_B 133 μa	h_{FE}, V_{BE} I_{CBO} V_{BE} V_{BE}

TABLE 2 - MANUFACTURER'S SPECIFICATION FOR TEST SPECIMENS		
Diode Type	V_F	I_R
HPA-1002	I_F 300 ma, T 25° C; V_F 1 VDC	V_R = 30 VDC, T = 25° C; I_R = 0.2 μa
1N1616	I_F 10 amps, T 25° C; V_F 1.5 VDC	V_R = 600 VDC, T = 25° C; I_R = 10 μa
Transistor Type	h_{FE}	I_{CBO}
S2N1724	V_{CE} 15 VDC, I_C 2.0 amps; h_{FE} = 20 to 90	V_{CB} = 175 VDC, T = 25° C; I_{CBO} = 10 ma
2N2222	V_{CE} 10 VDC, I_C 150 ma; h_{FE} 100 to 300	V_{CB} = 50 VDC, T = 25° C; I_{CBO} = .01 μa
Integrated Circuit Type	V_{out} — No Load	V_{out} — Load (n = 20)
Flip Flop SN511	V_{CC} = 6 VDC On Level V_{out} = 0.35 VDC Off Level V_{out} = 4.1 VDC	V_{CC} = 6 VDC On Level V_{out} = 0.35 VDC Off Level V_{out} = 3.8 VDC
Amplifier SN522	GAIN	
	+ + V_{CC} = 10 ± 0.2 VDC + V_{CC} = 6 ∓ 0.2 VDC - V_{CC} = -9 ∓ 0.2 VDC	Gain = 54 db to 62 db

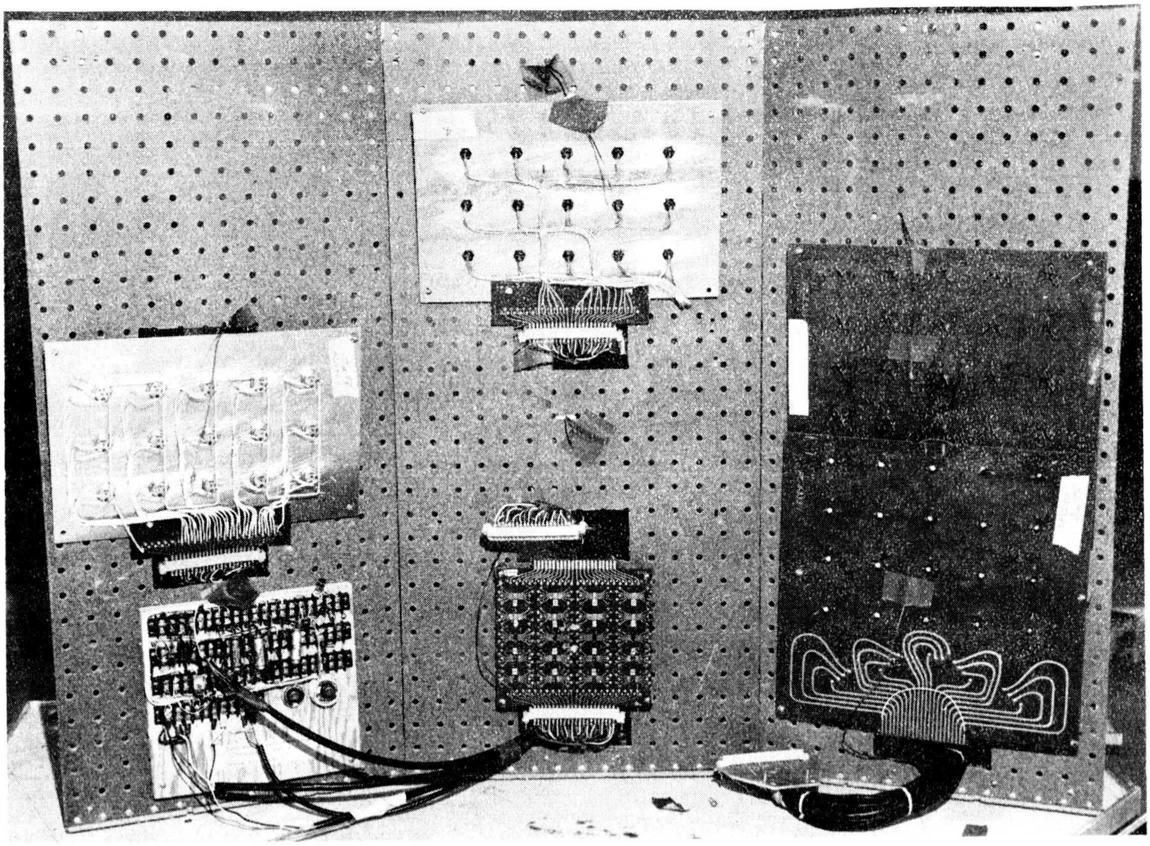

FIGURE 1 IRRADIATION TEST PANEL

( ) Gamma monitors located in rear of test panels
O Temperature monitor
X Neutron Monitor foils

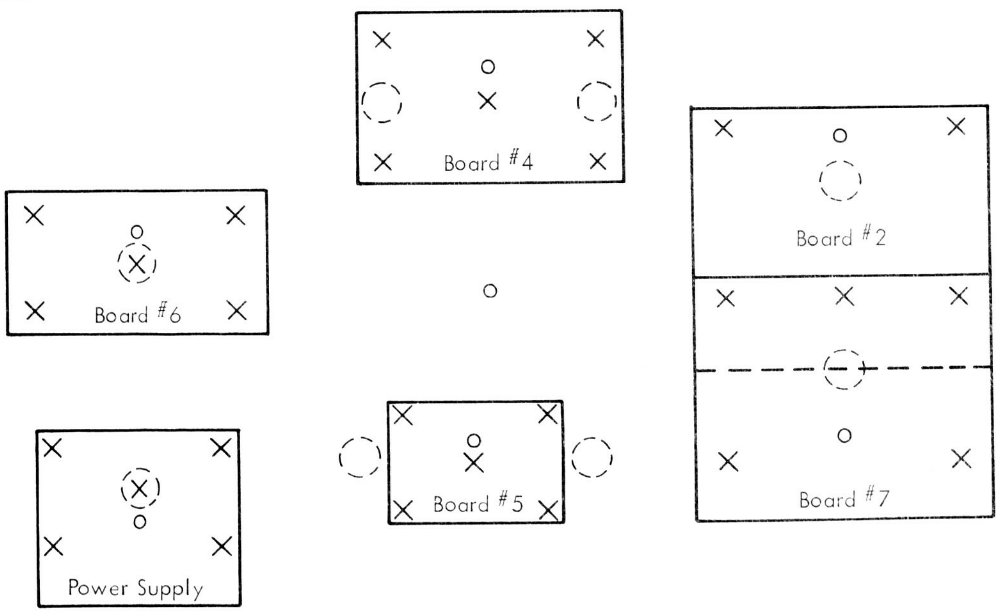

FIGURE 2 - TEST CONFIGURATION AS SEEN FROM REACTOR

DIODE	I
HPA-1002	134 ma 290 ma
1N1616	1.07 amps 2.19 amps

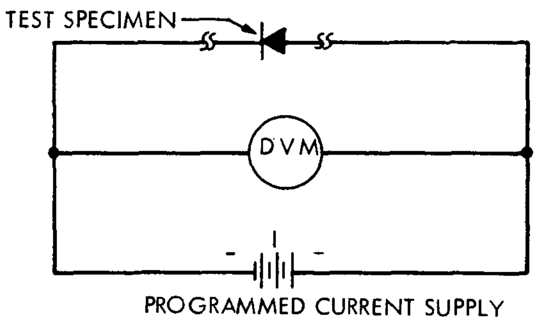

FIGURE 3 V_F MEASUREMENT CIRCUIT

DIODE	E
HPA-1002	30 VDC
1N1616	600 VDC

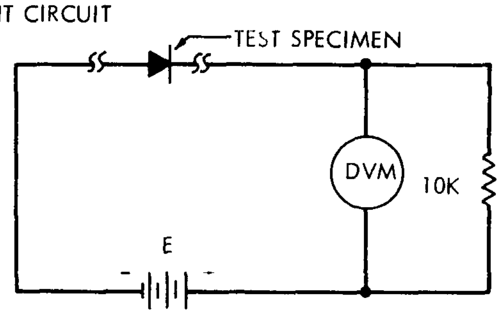

FIGURE 4 I_R MEASUREMENT CIRCUIT

TRANSISTOR	E
S2N1724	84 VDC
2N2222	50 VDC

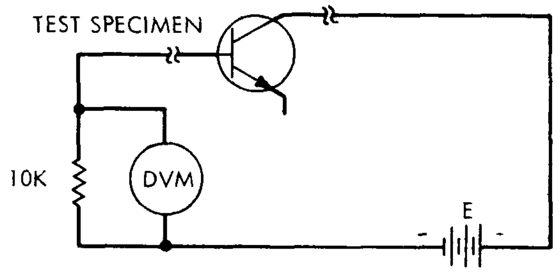

FIGURE 5 I_{CBO} MEASUREMENT CIRCUIT

Transistor	E_C	R_E	R_C	R_F
S2N1724	30	0.5	4.0	1.34
2N2222	30	10	1.8K	134

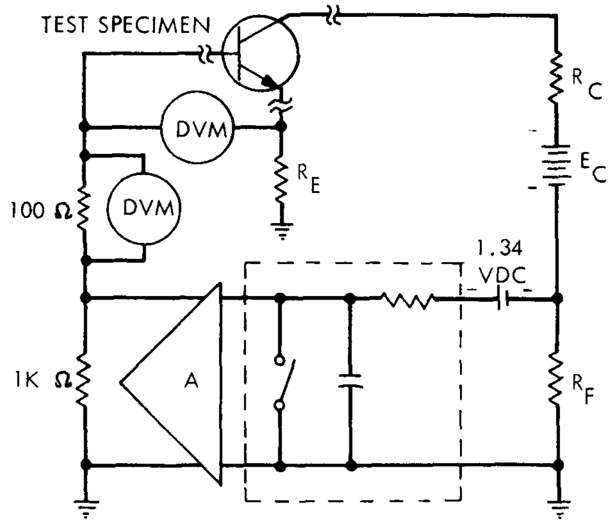

FIGURE 6 h_{FE} AND V_{BE} MEASUREMENT CIRCUIT

Transistor	E_C	E_B	R_B	R_E
S2N1724	20	39.5	1.31K	0.5
	20	39.5	2.00K	0.5
2N2222	10	37.5	573K	10
	10	38.4	297K	10

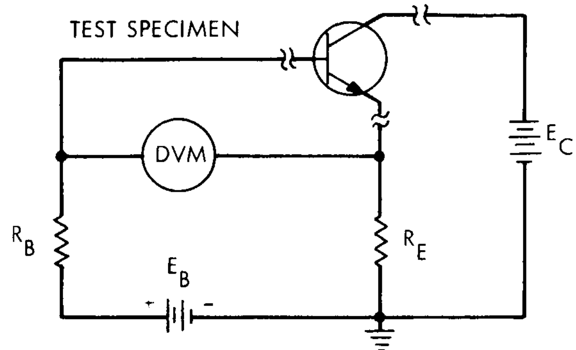

FIGURE 7 V_{BE} MEASUREMENT CIRCUIT; I_B = CONSTANT

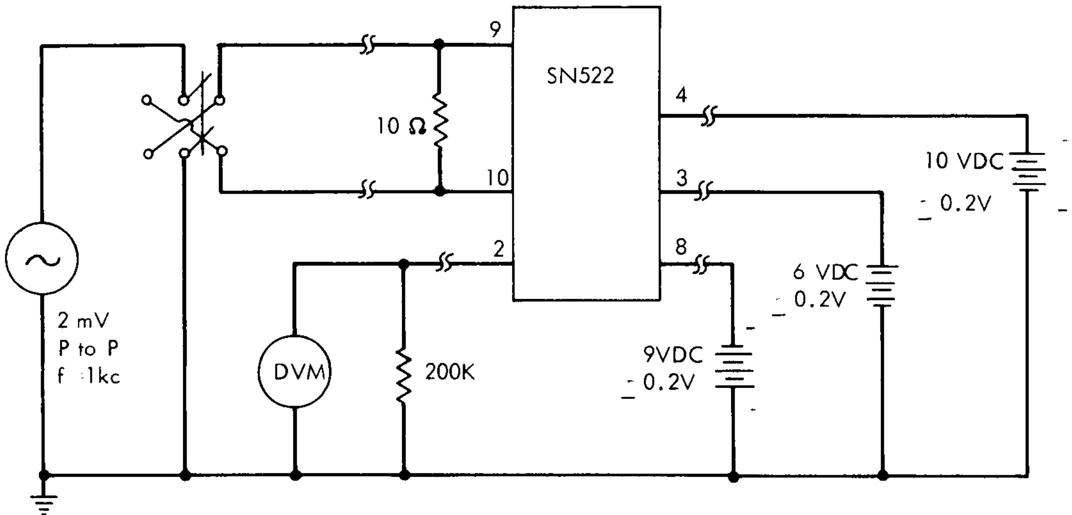

FIGURE 8 AMPLIFIER, SN522, MEASUREMENT CIRCUIT

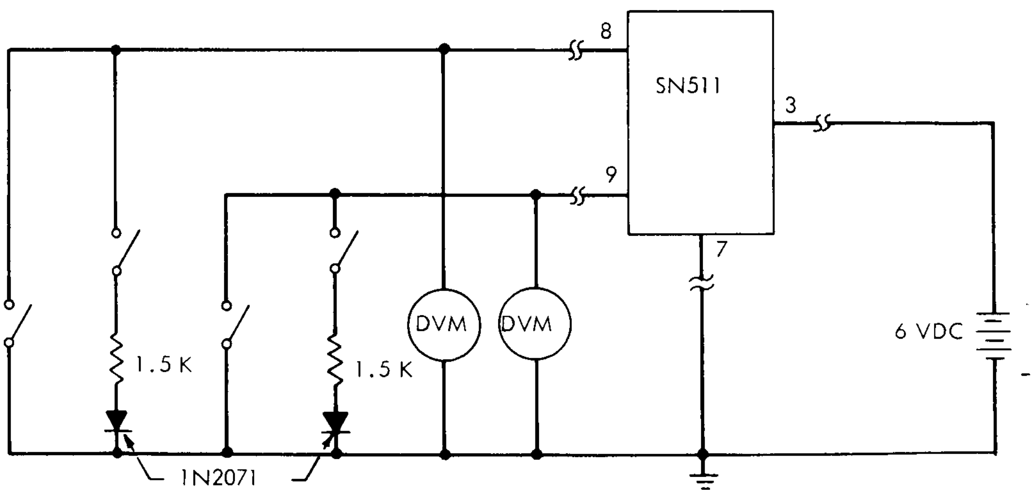

FIGURE 9 FLIP FLOP, SN511, MEASUREMENT CIRCUIT

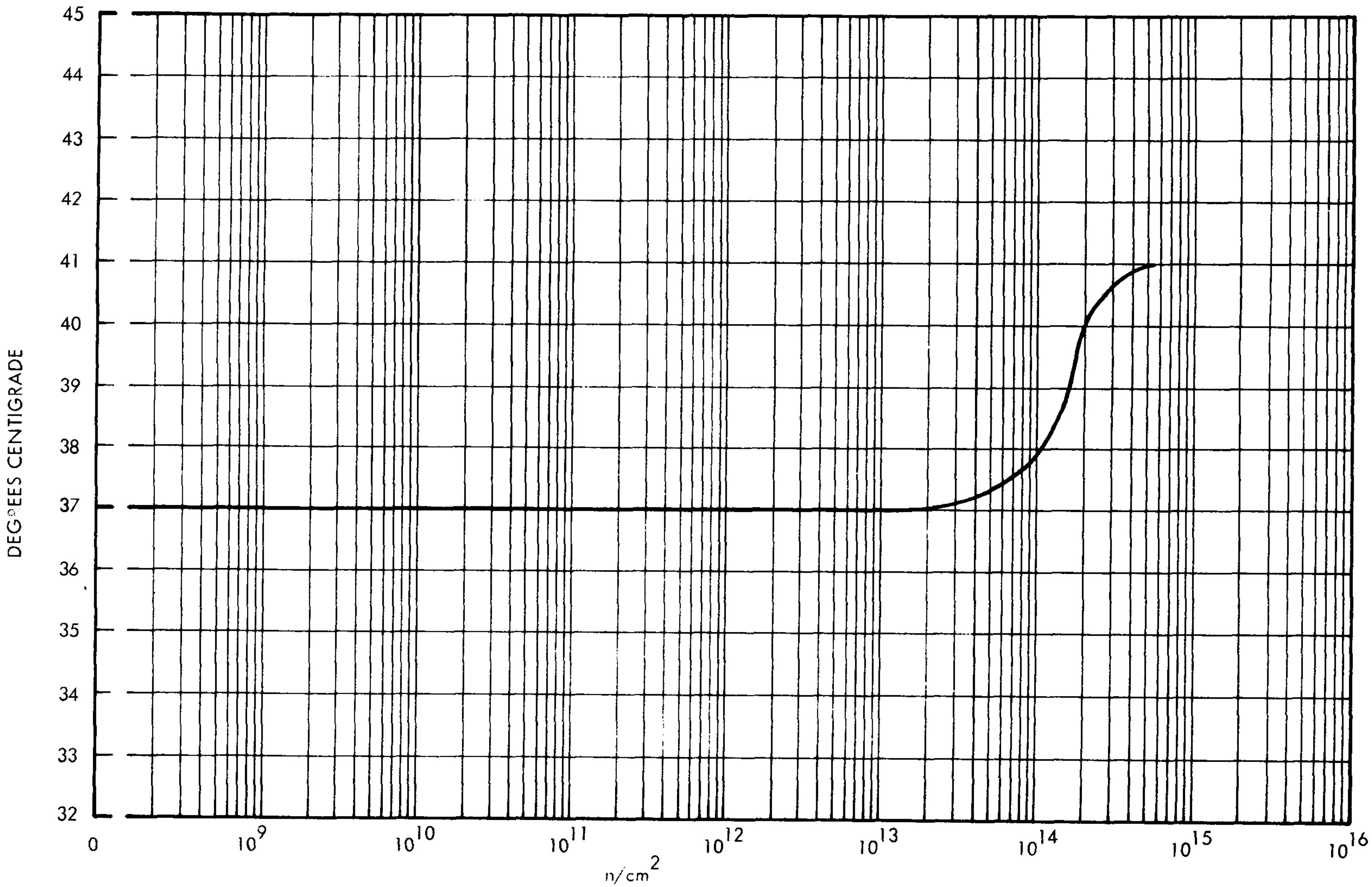

FIGURE 10 ENVIRONMENTAL TEMPERATURE VERSUS INTEGRATED NEUTRON FLUX

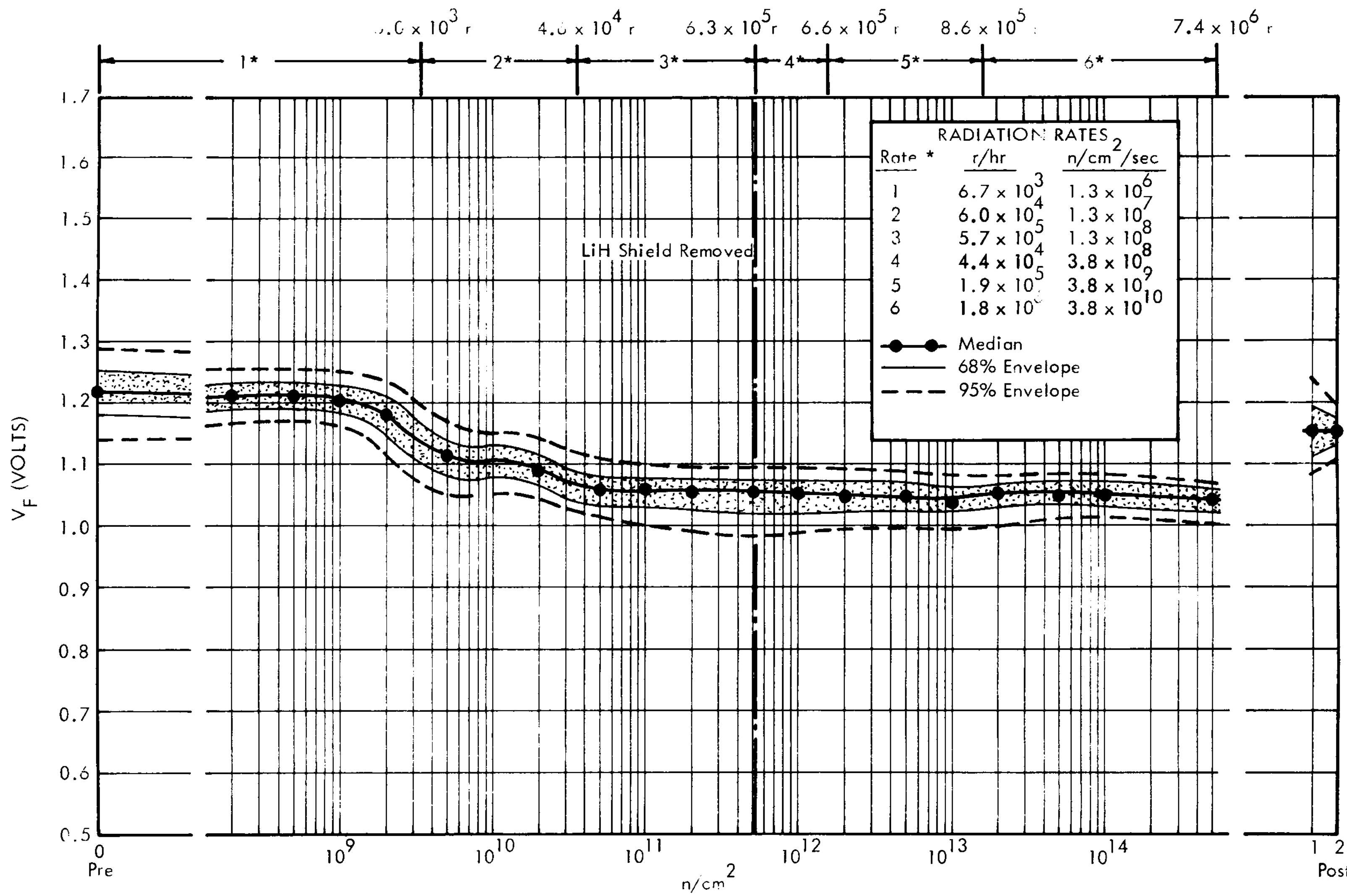

FIGURE 11 HPA 1002, V_F (I_F = 134 ma) VERSUS INTEGRATED NEUTRON FLUX AT T = 37 $\pm$ 0.5° C (15 SPECIMENS)

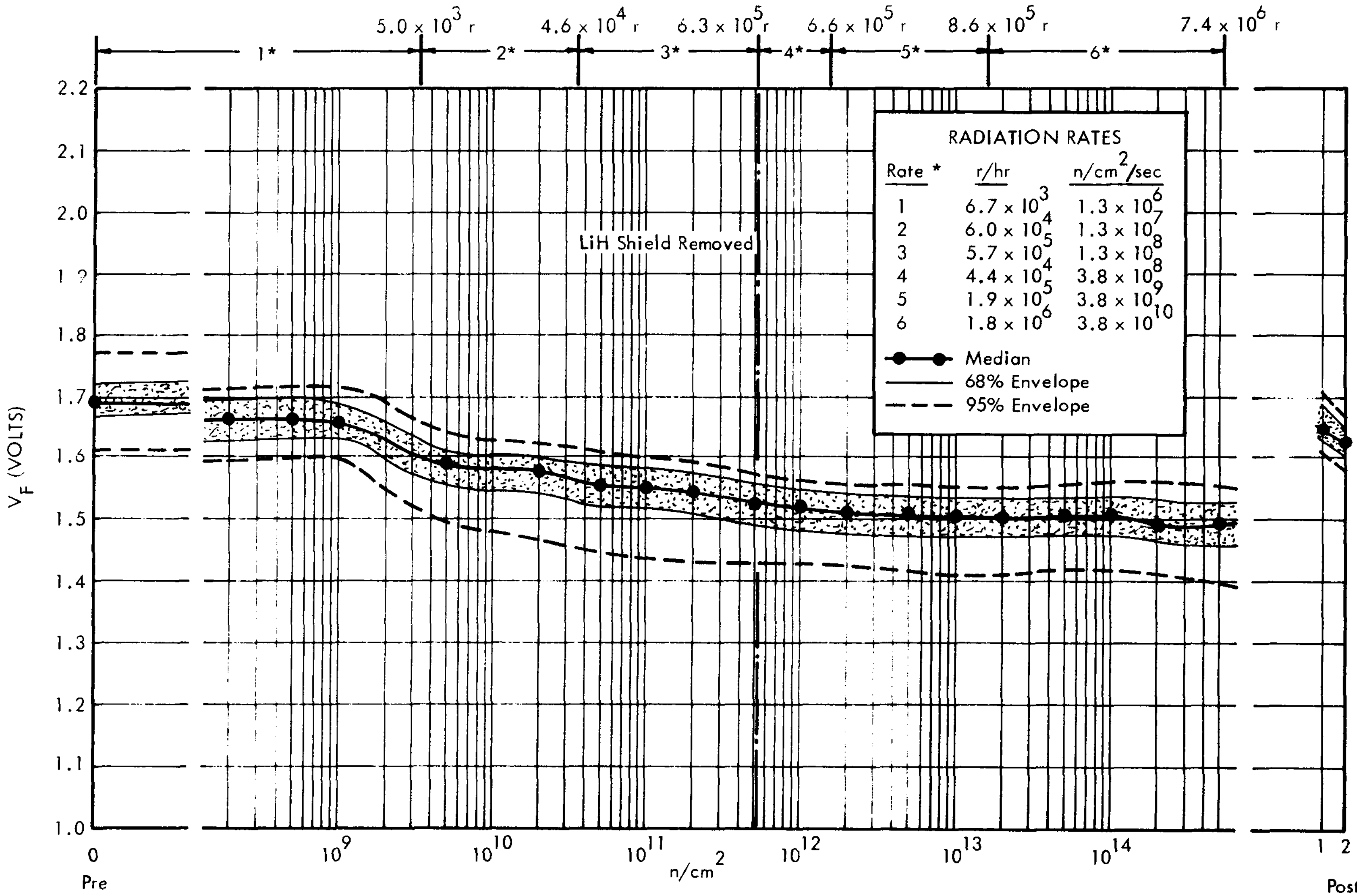

FIGURE 12 HPA 1002, V_F (I_F = 290 ma) VERSUS INTEGRATED NEUTRON FLUX AT T = 37 $\pm$ 0.5° C (15 SPECIMENS)

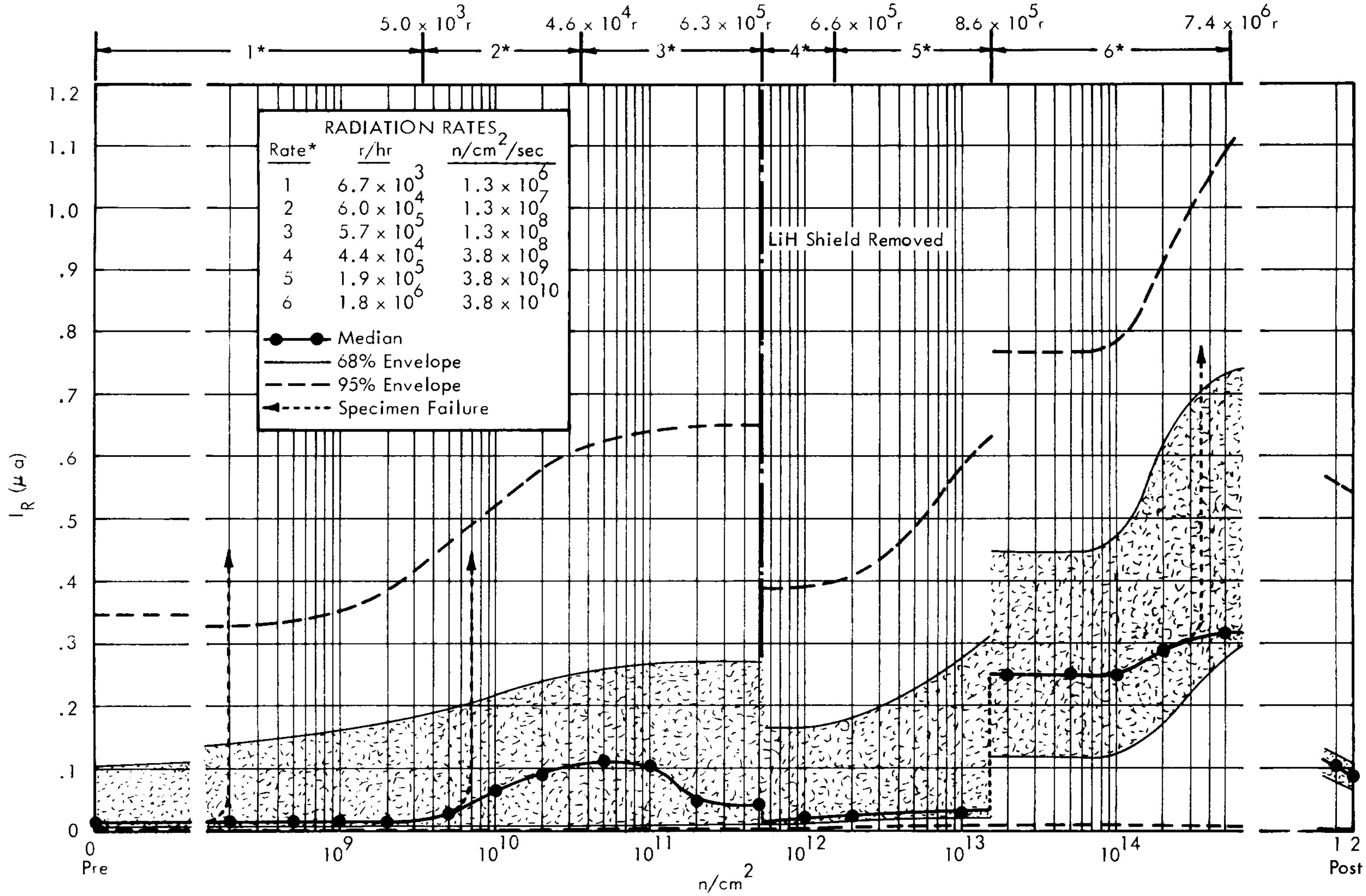

FIGURE 13 HPA 1002, I_R VERSUS INTEGRATED NEUTRON FLUX AT T 37 _ 0.5° C (15 SPECIMENS)

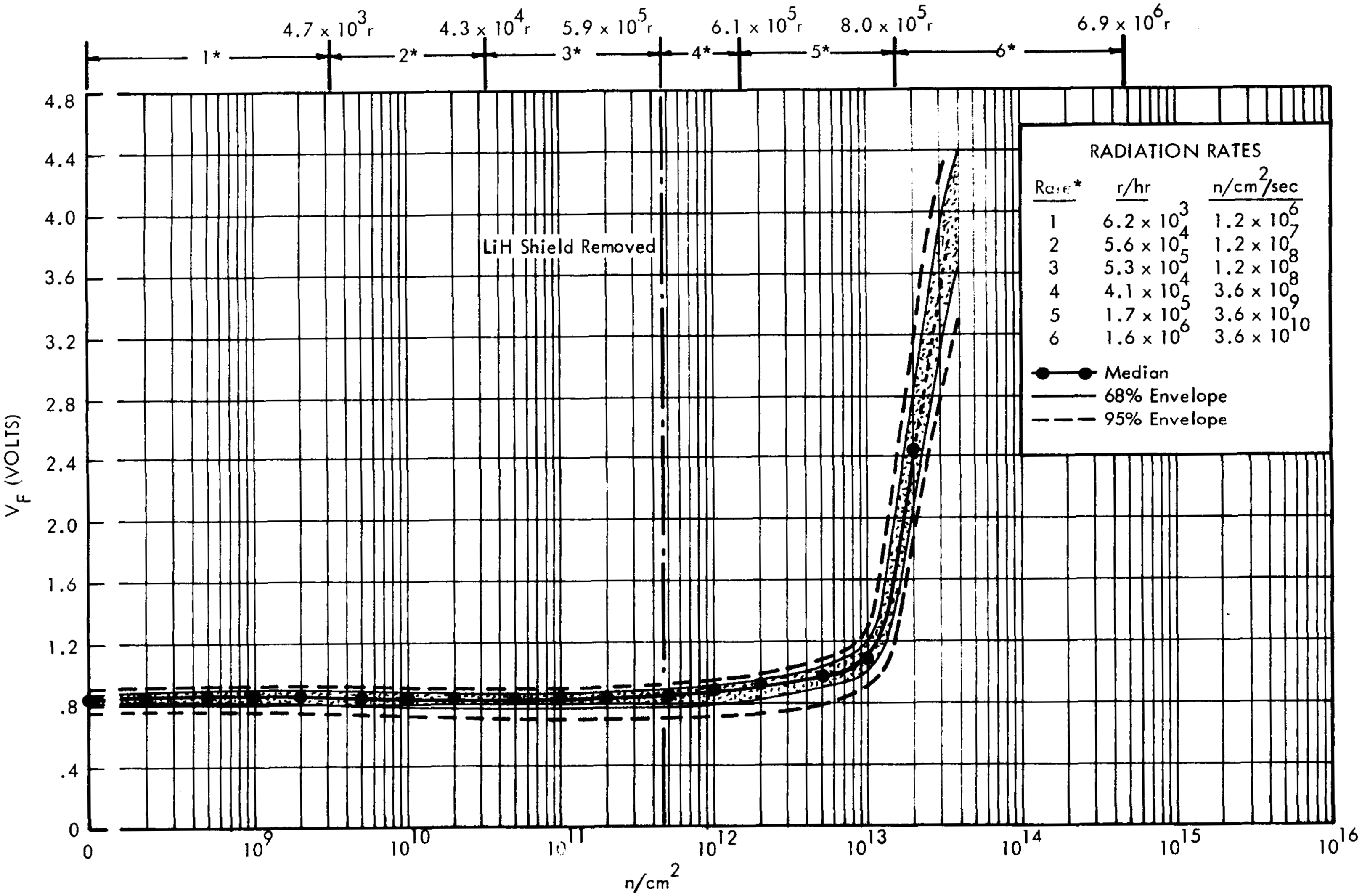

FIGURE 14 1N1616, V_F (I_F 1.07A) VERSUS INTEGRATED NEUTRON FLUX AT T 37 _ 0.5° C (11 SPECIMENS)

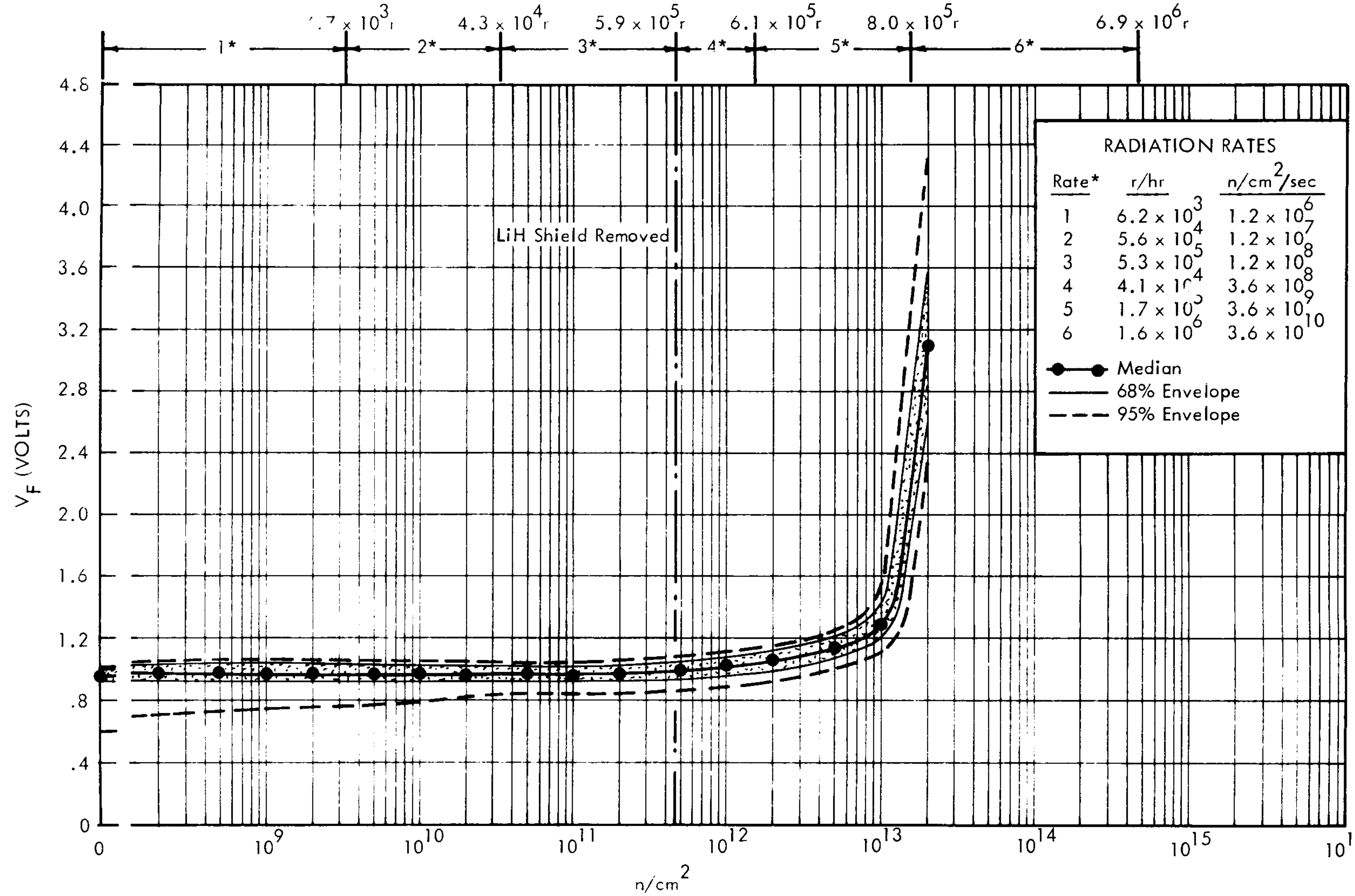

FIGURE 15 1N1616, V_F (I_F = 2.20A) VERSUS INTEGRATED NEUTRON FLUX AT T = 37 ± 0.5° C (11 SPECIMENS)

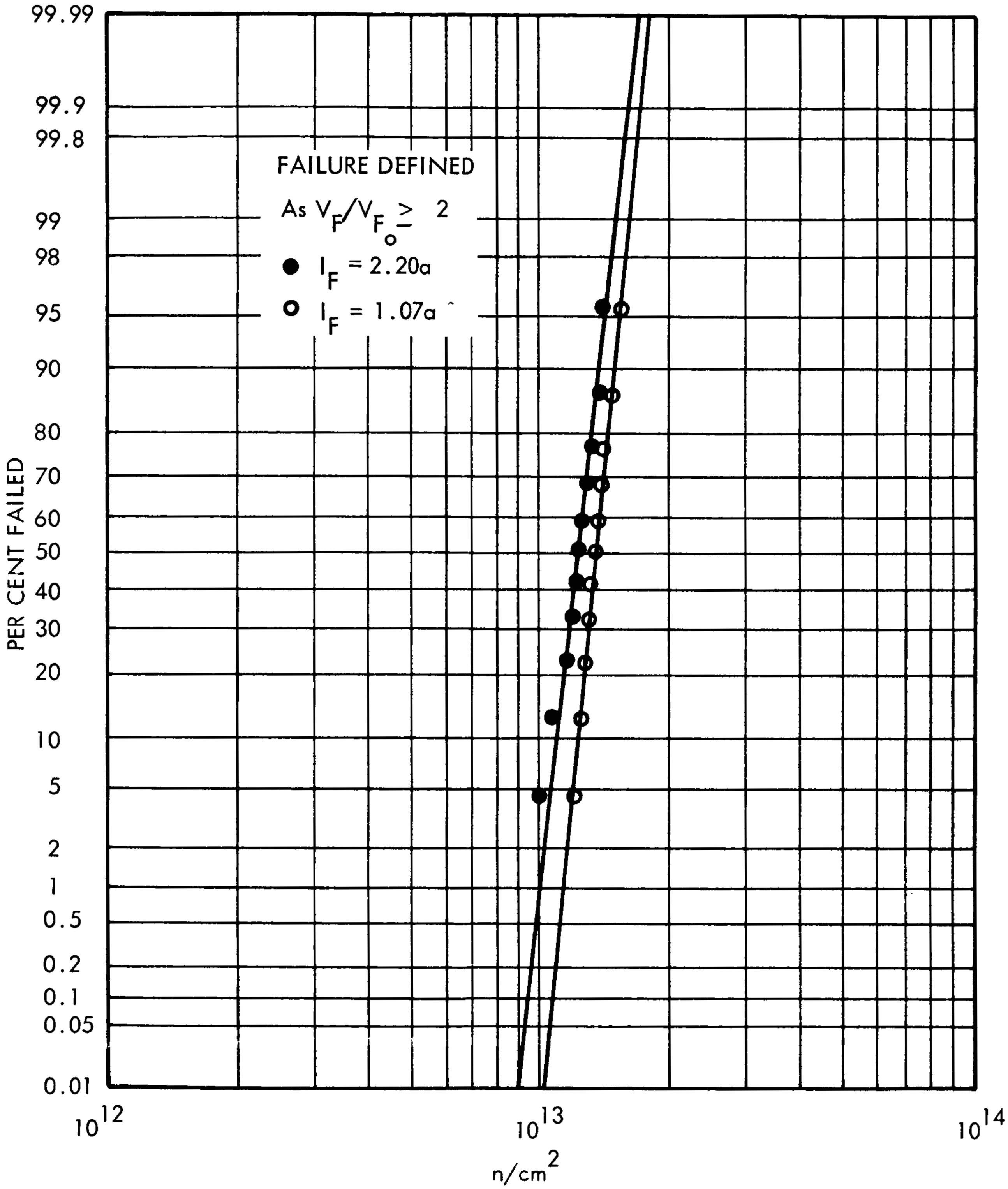

FIGURE 16 1N1616 PER CENT FAILED VERSUS INTEGRATED NEUTRON FLUX AT T = 37 $\pm$ 0.5° C

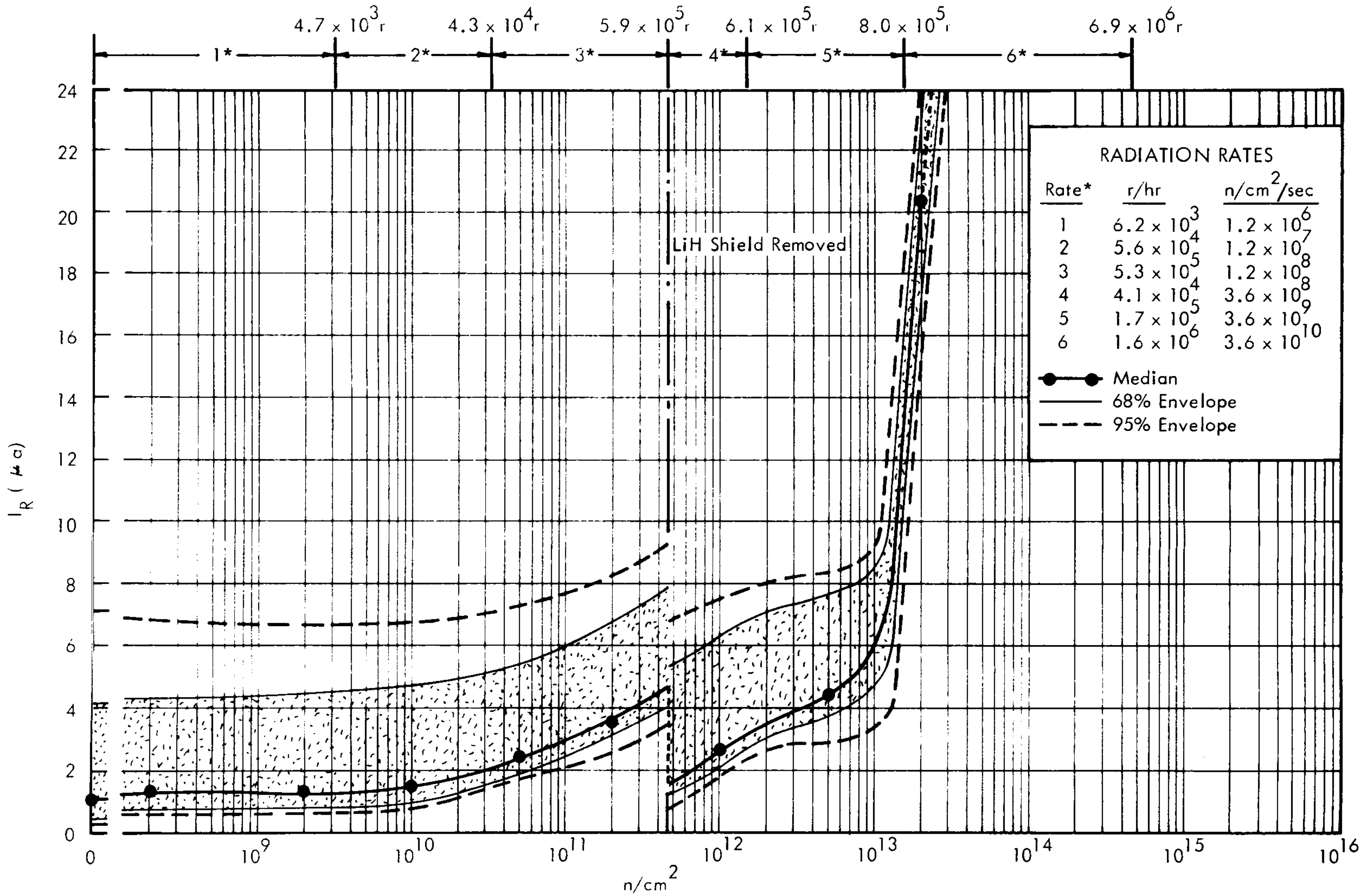

FIGURE 17 1N161$\cdot$, I_R VERSUS INTEGRATED NEUTRON FLUX AT T 37 $\pm$ 0.5° C (11 SPECIMENS)

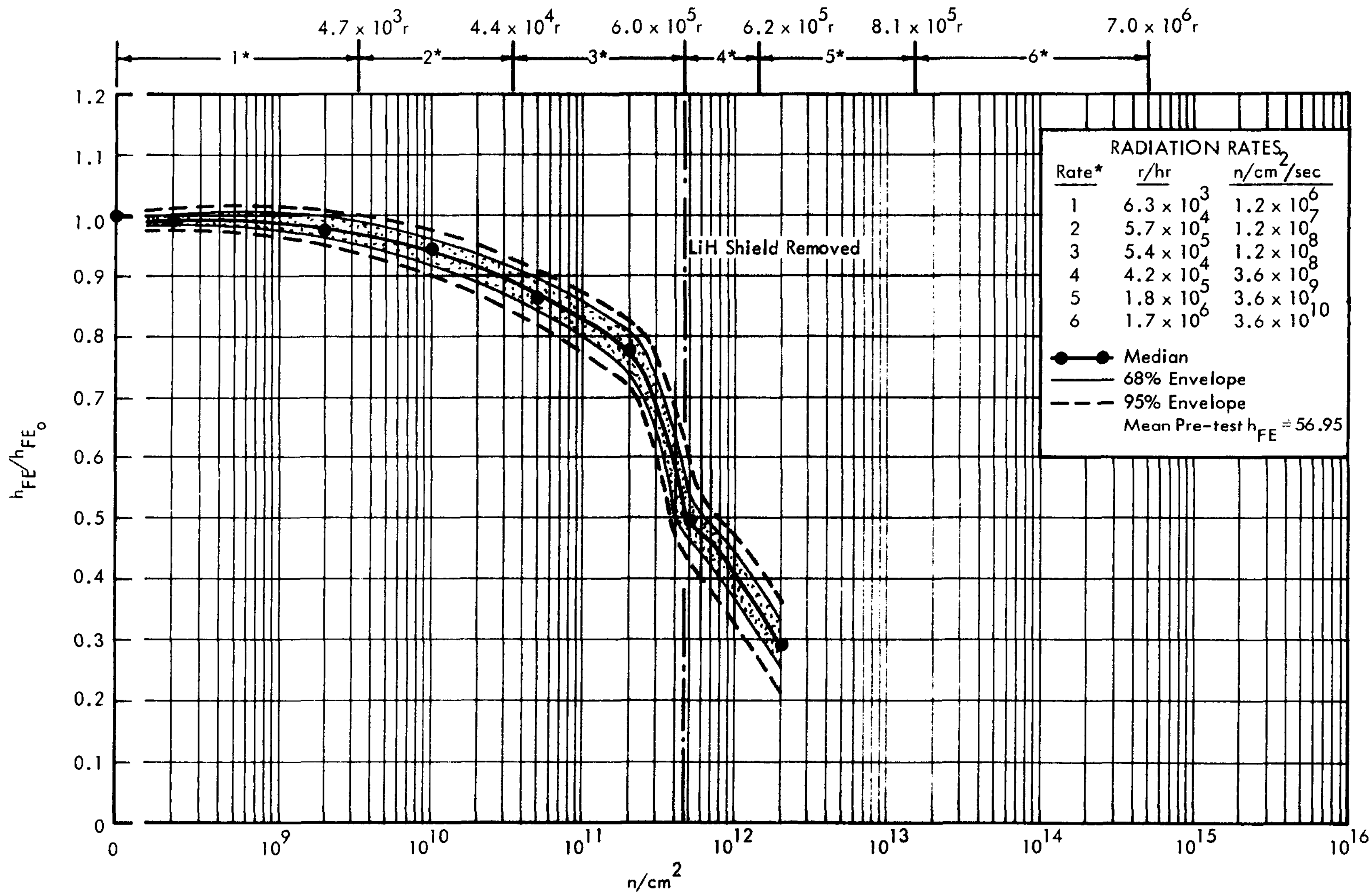

FIGURE 18 S2N1724, NORMALIZED h_{FE} VERSUS INTEGRATED NEUTRON FLUX AT T = 37 ± 0.5° C (10 SPECIMENS)

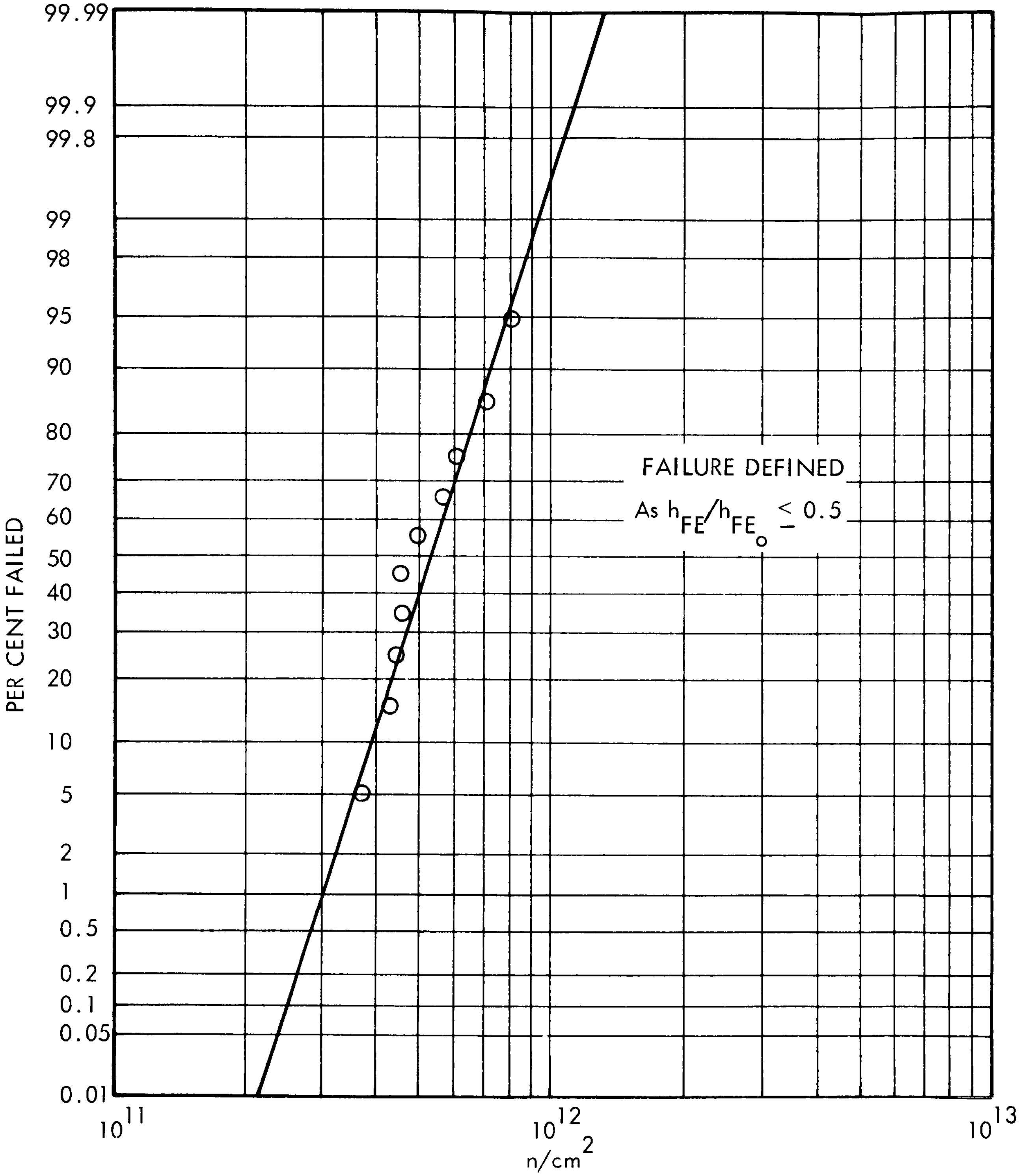

FIGURE 19 S2N1724, PER CENT FAILED VERSUS INTEGRATED NEUTRON FLUX AT T = 37 $\pm$ 0.5° C

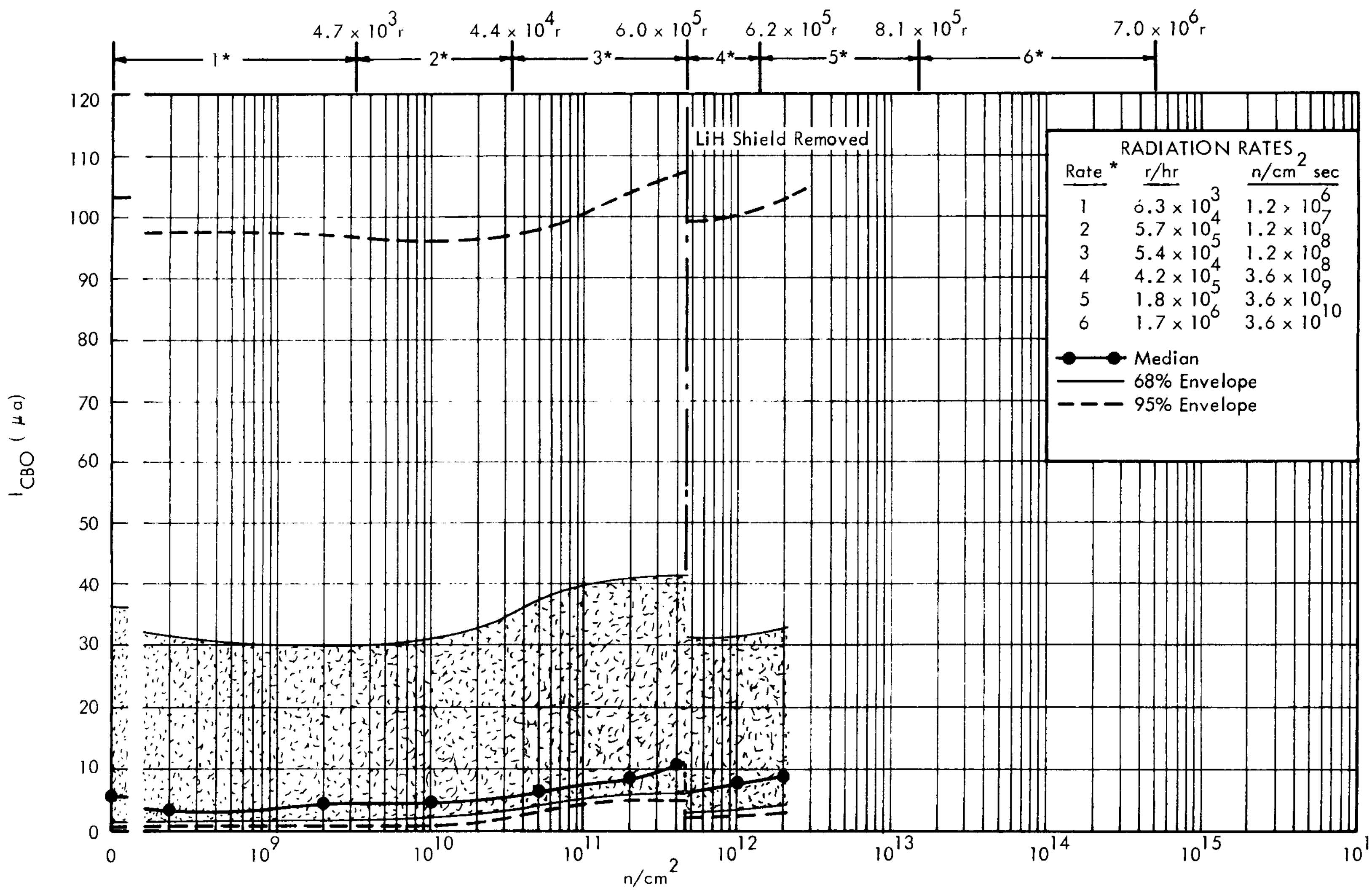

FIGURE 20 S2N1724, I_{CBO} VERSUS INTEGRATED NEUTRON FLUX AT T = 37 ± 0.5° C (13 SPECIMENS)

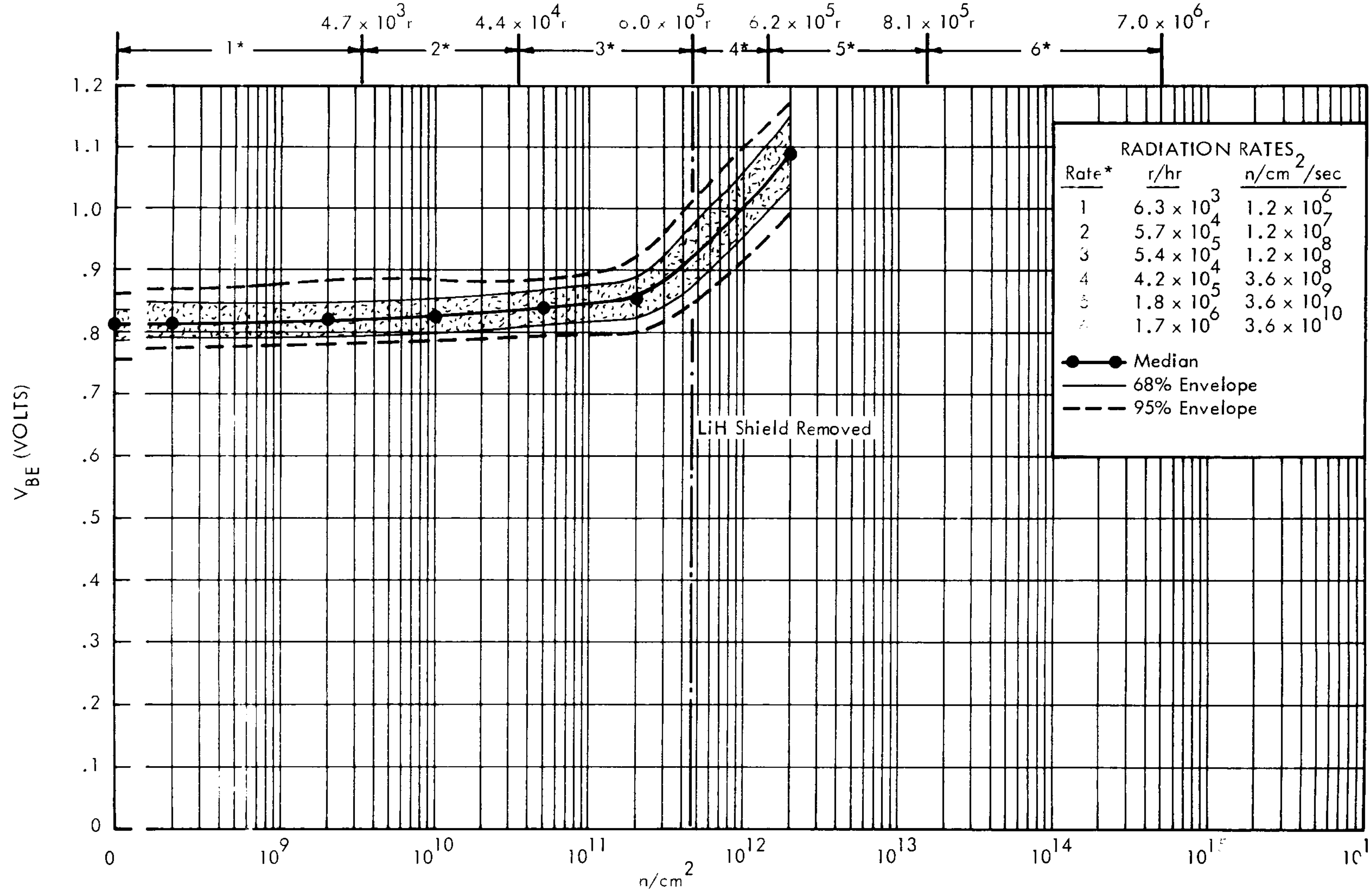

FIGURE 21 S2N1724, V_{BE} (I_C 1A CONSTANT) VERSUS INTEGRATED NEUTRON FLUX AT T = 37 ± 0.5° C (13 SPECIMENS)

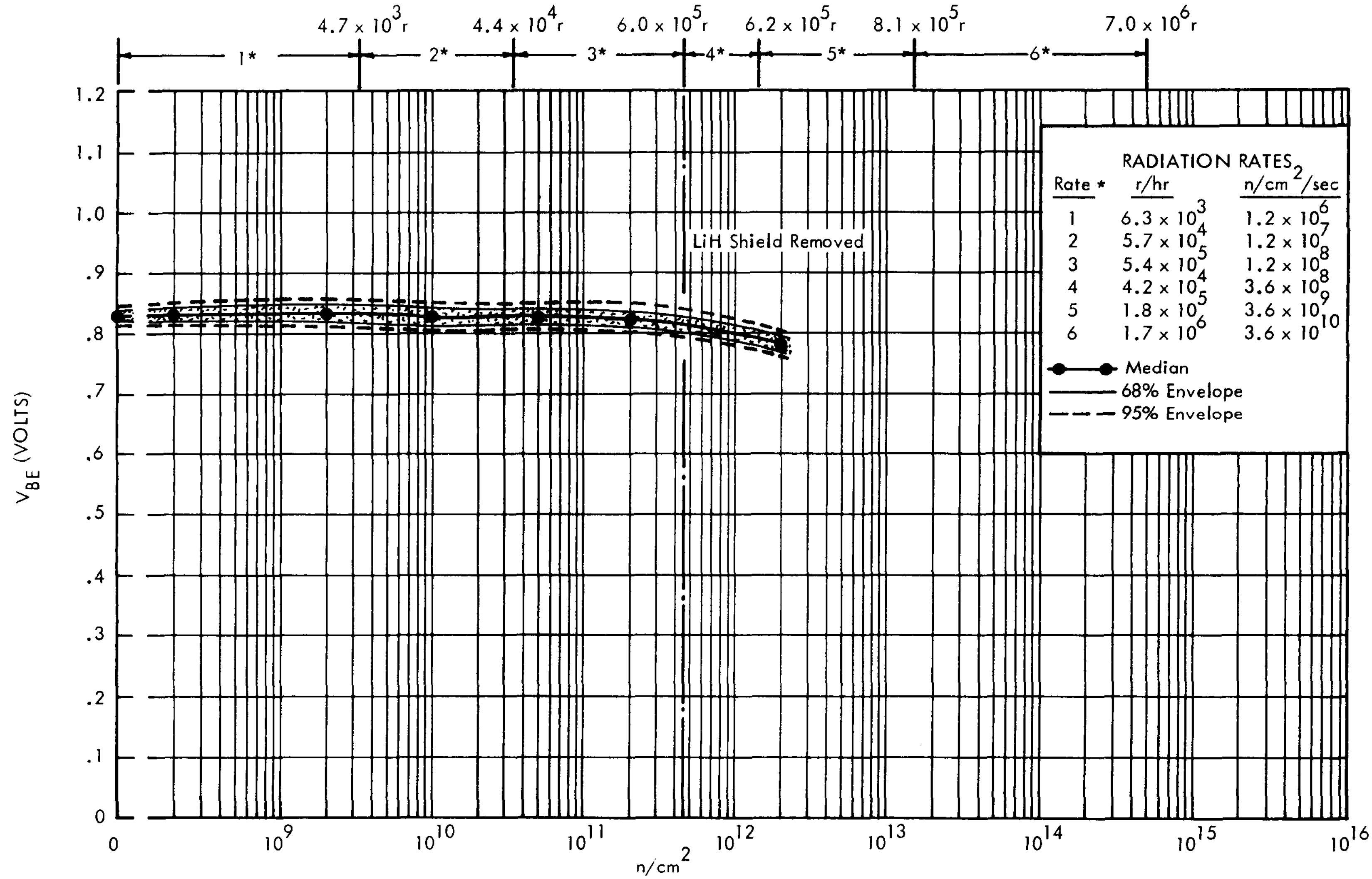

FIGURE 22 S2N1724, V_{BE} (I_B CONSTANT, MEAN I_C .75 A) VERSUS INTEGRATED NEUTRON FLUX AT T = 37 $\pm$ 0.5° C (13 SPECIMENS)

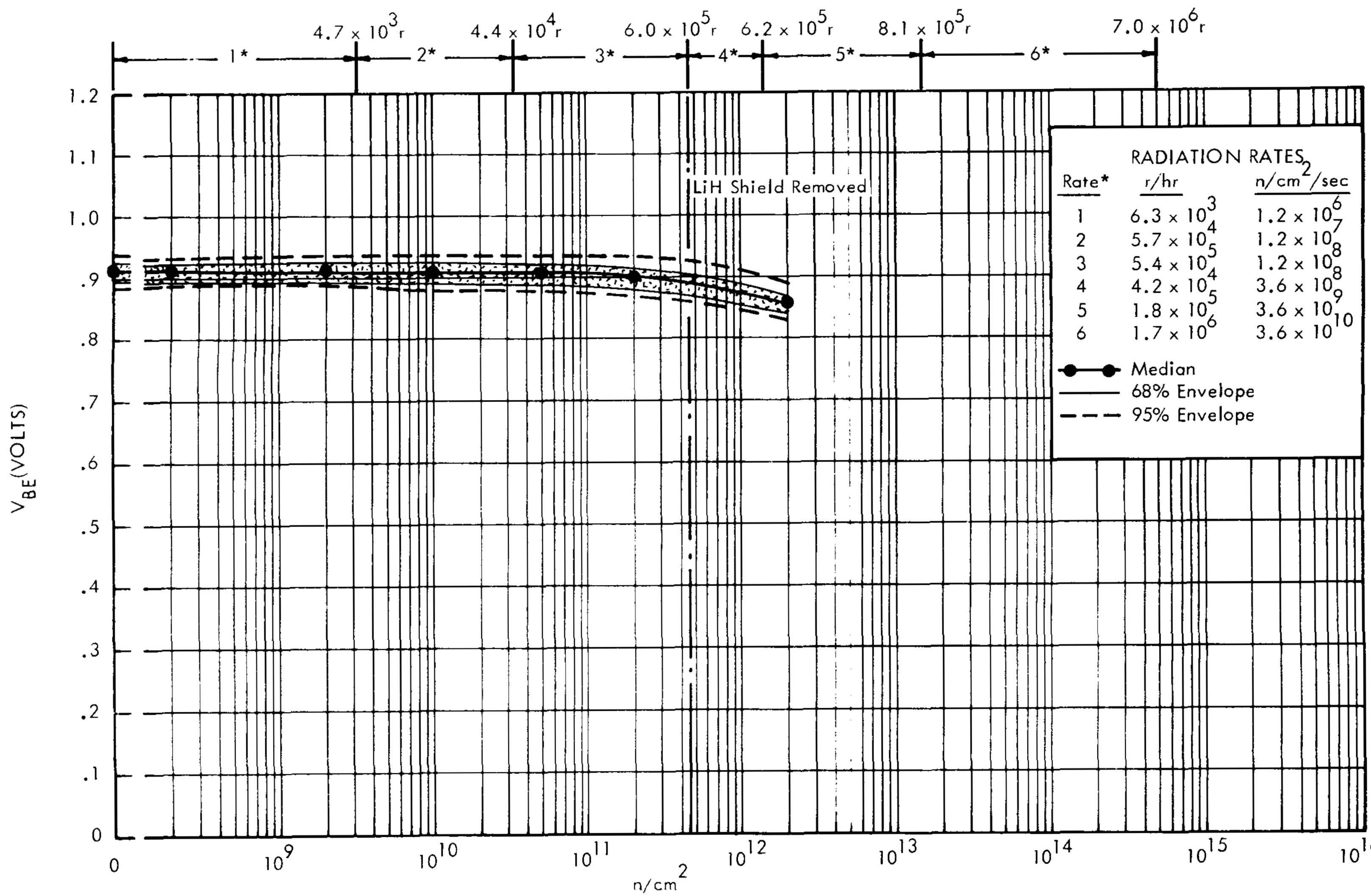

FIGURE 2ː S2N1724, V_{BE} (I_B CONSTANT, MEAN I_C 1A) VERSUS INTEGRATED NEUTRON FLUX AT T 37 _ 0.5° C (13 SPECIMENS)

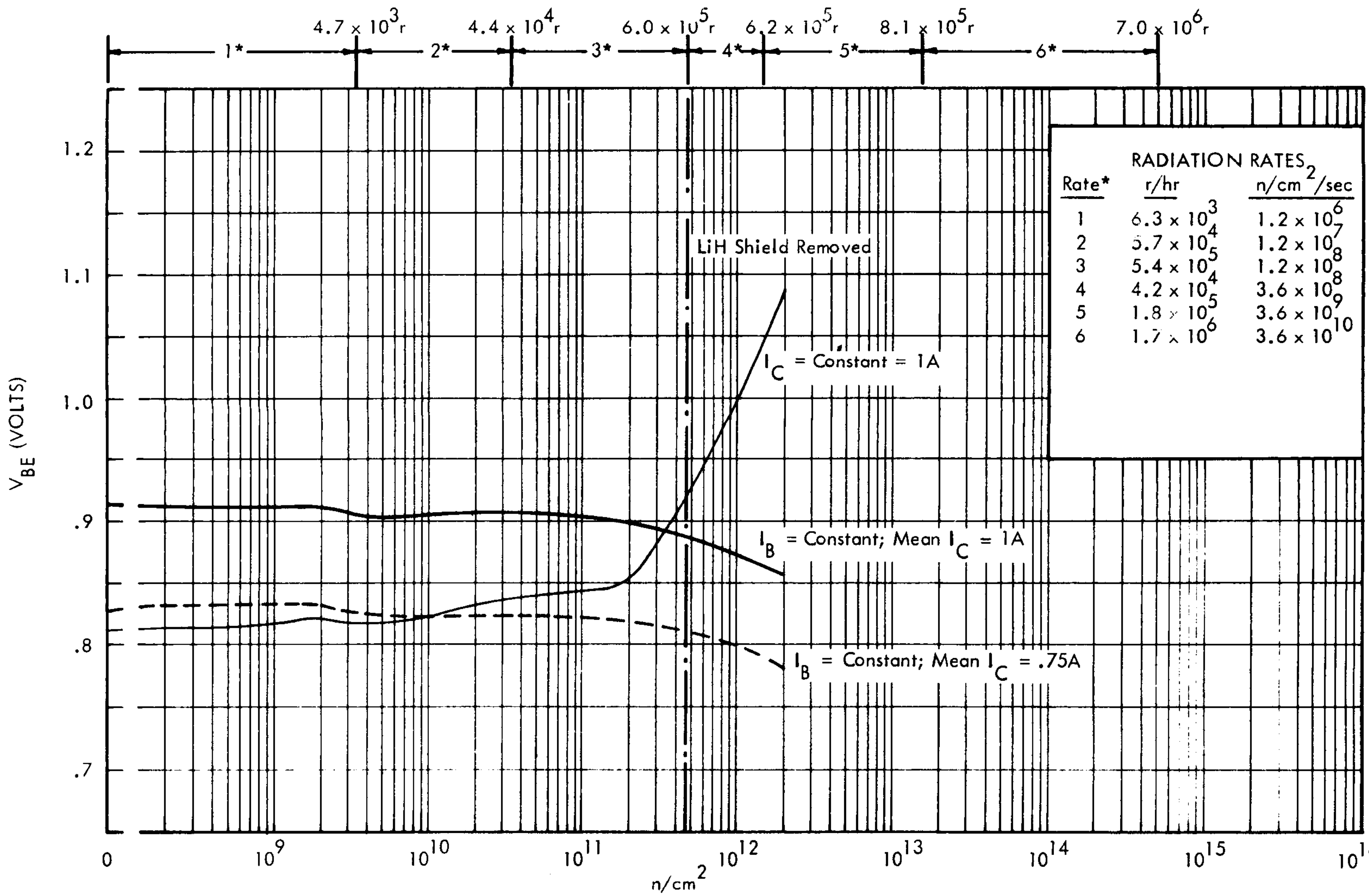

FIGURE 24 S2N1724 MEDIAN V_{BE} VERSUS INTEGRATED NEUTRON FLUX AT T = 37 $\pm$ 0.5° C (13 SPECIMENS)

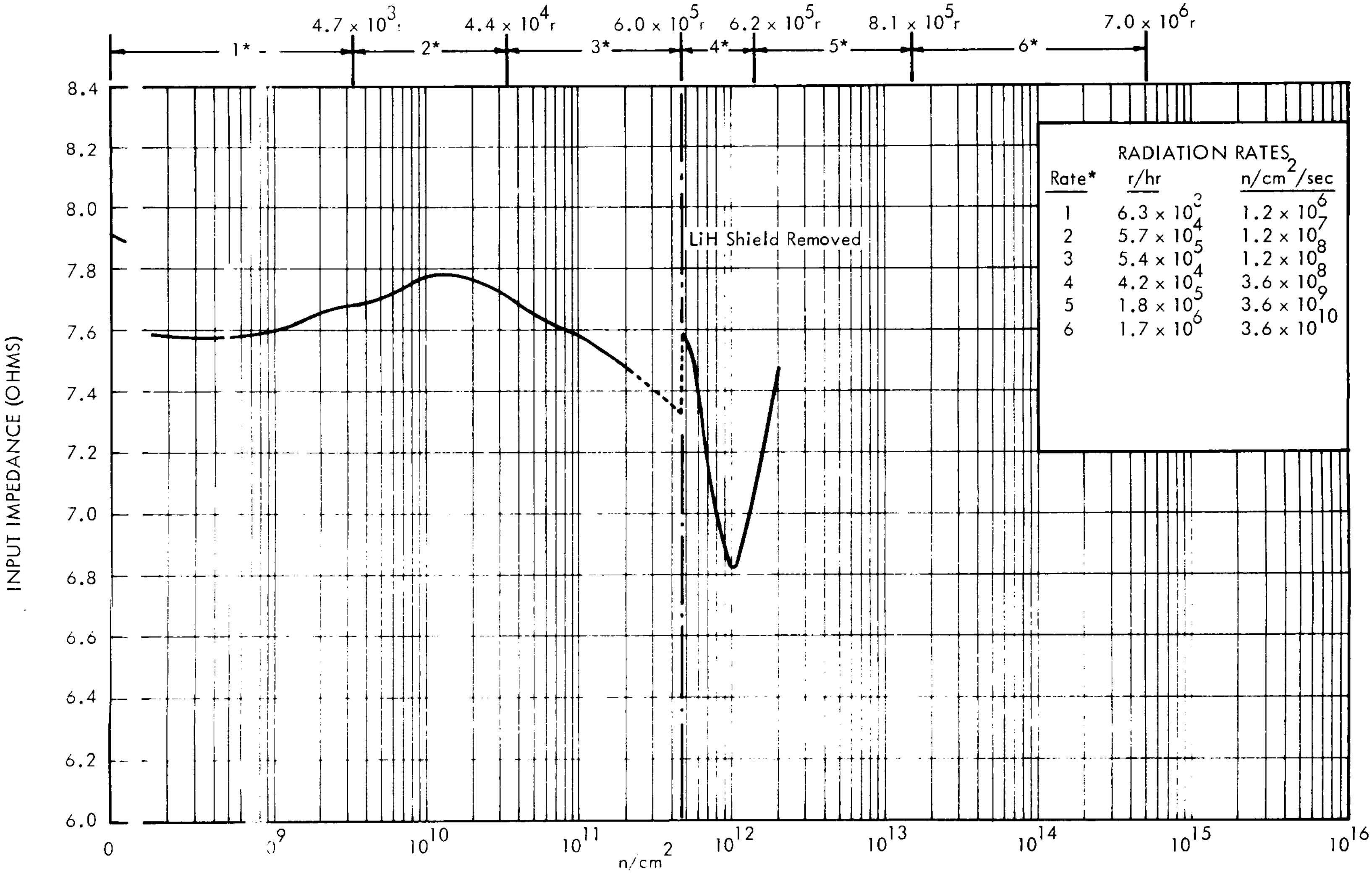

FIGURE 25 S2N1724, INPUT IMPEDANCE VERSUS INTEGRATED NEUTRON FLUX AT T = 37 ± 0.5° C

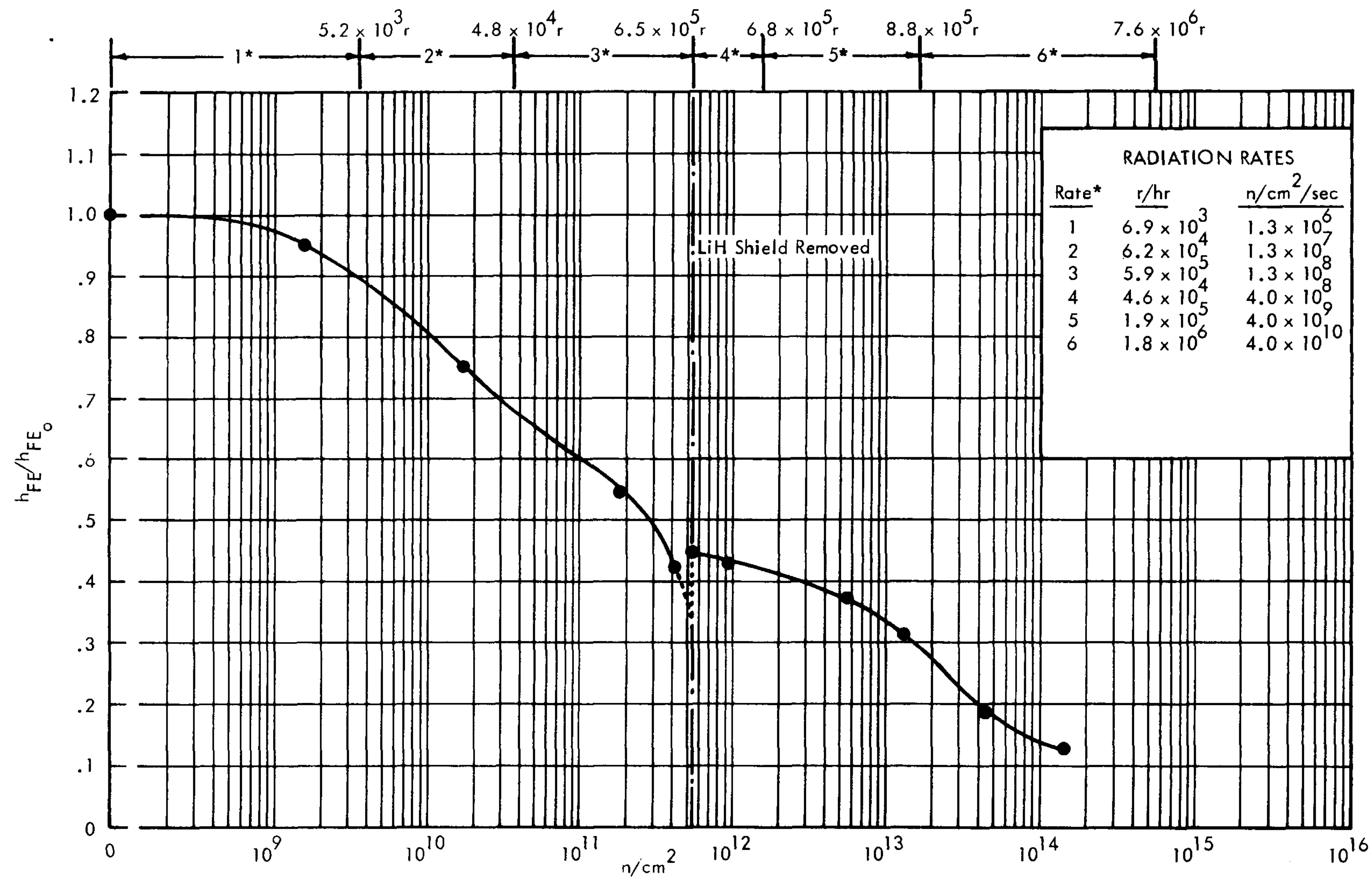

FIGURE 26 2N2222, NORMALIZED h_{FE} VERSUS INTEGRATED NEUTRON FLUX AT T 37 $\pm$ 0.5° C

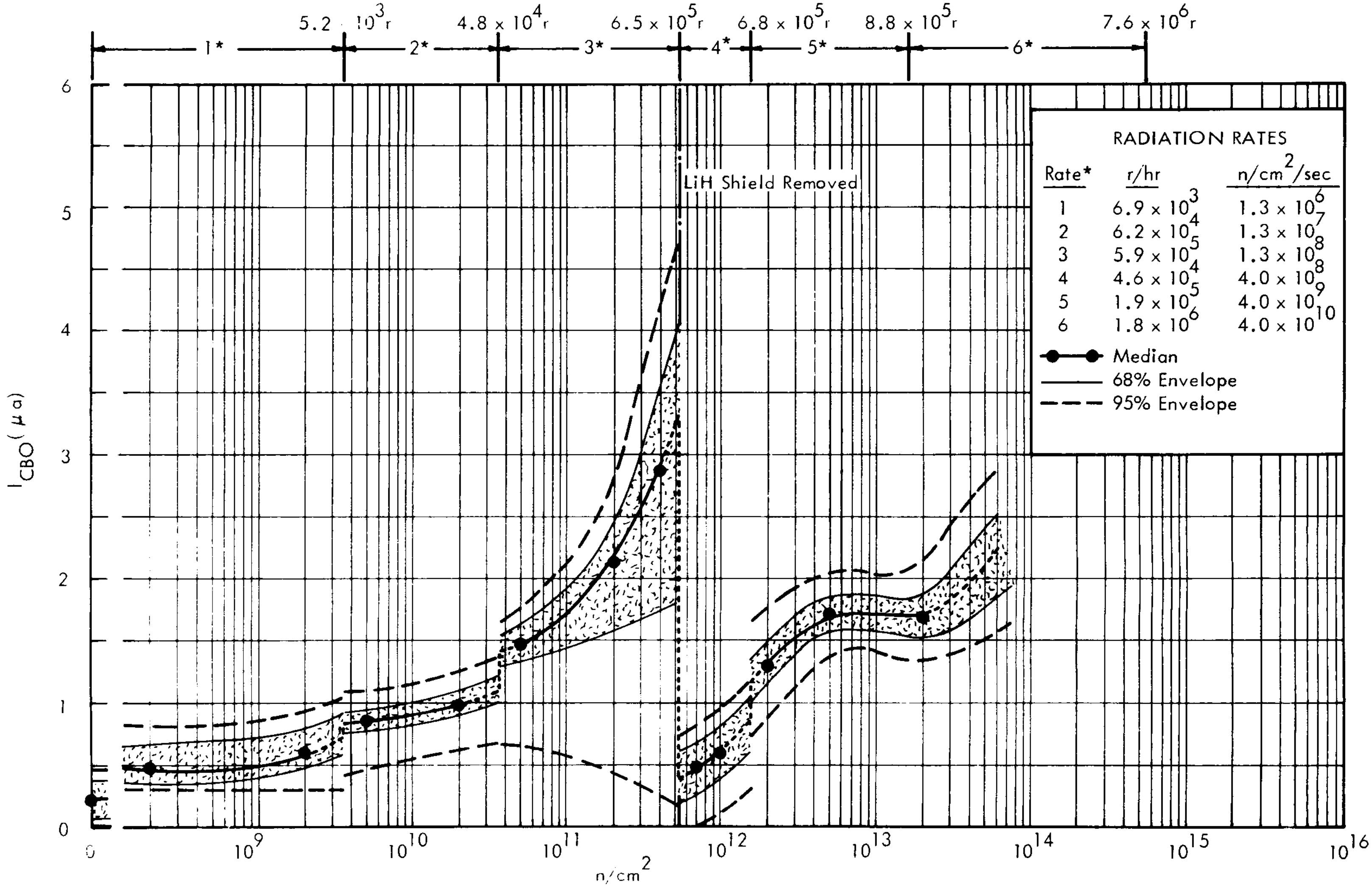

FIGURE 27, 2N2222, I_{CBO} VERSUS INTEGRATED NEUTRON FLUX AT T = 37 $\pm$ 0.5° C (14 SPECIMENS)

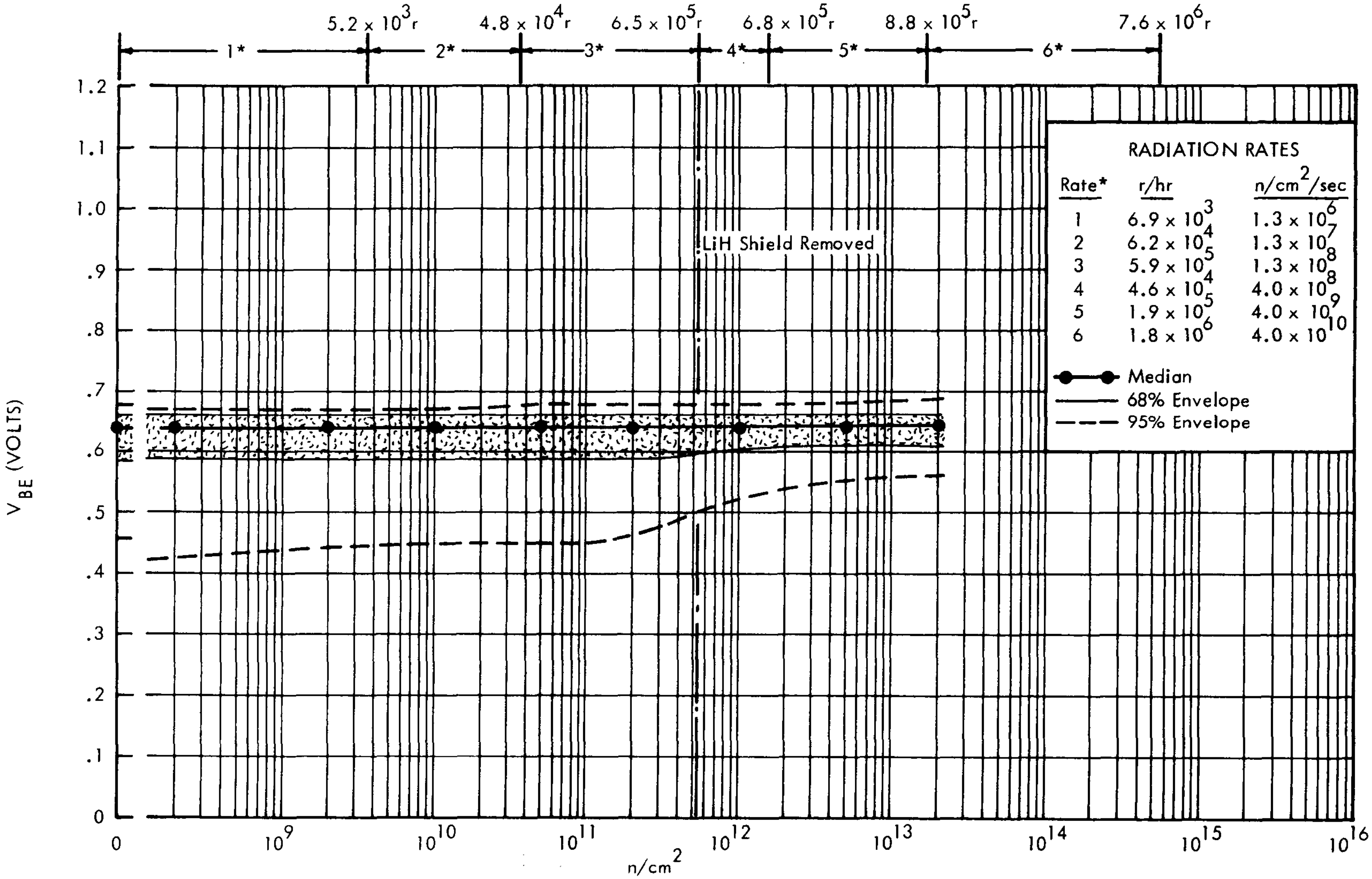

FIGURE 28 2N2222, V_{BE} (I_C 10 ma CONSTANT) VERSUS INTEGRATED NEUTRON FLUX AT T 37 $\pm$ 0.5° C (13 SPECIMENS)

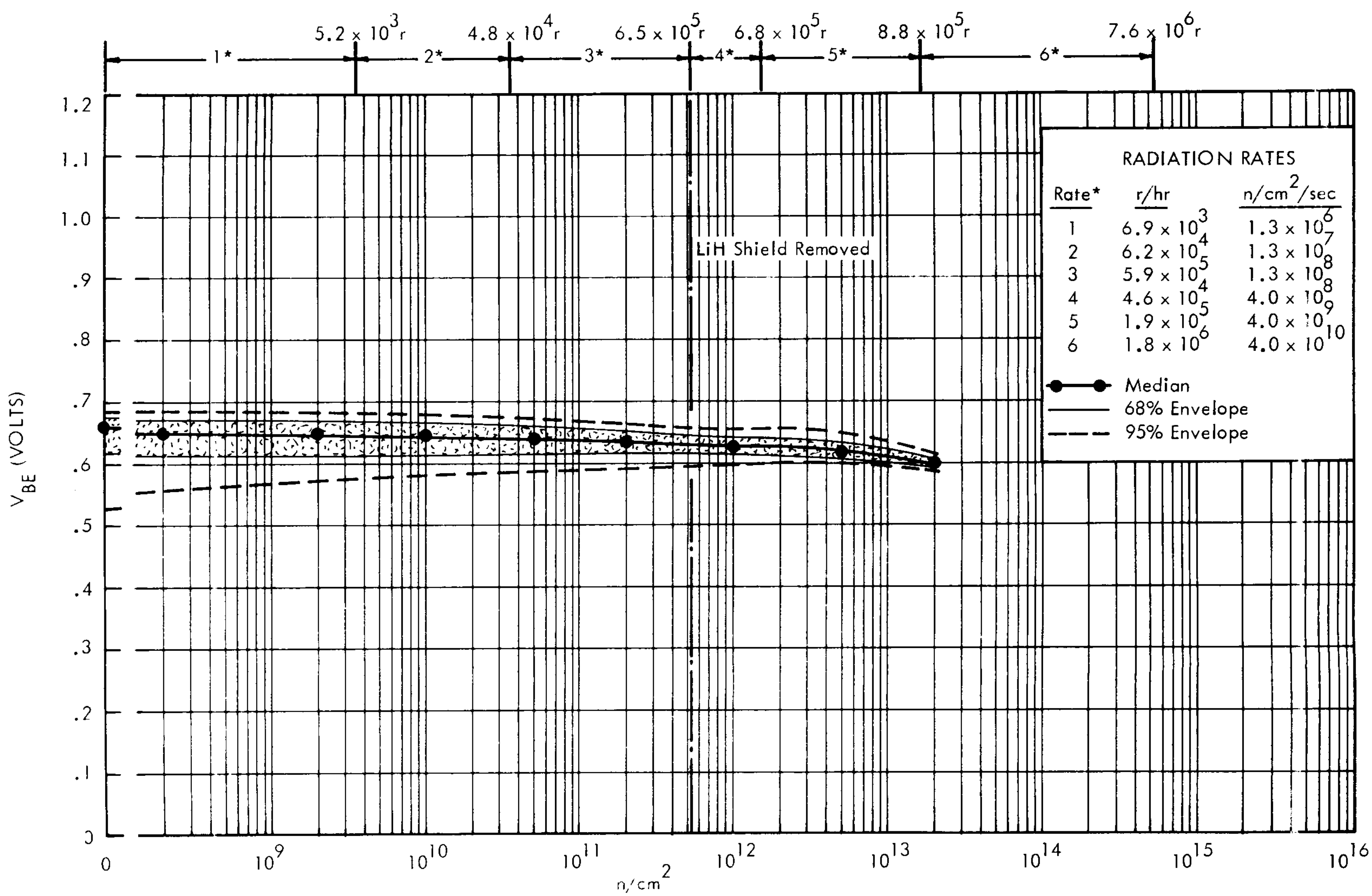

FIGURE 29 2N2222, V_{BE} (I_B CONSTANT, MEAN I_C = 10 ma) VERSUS INTEGRATED NEUTRON FLUX AT T = 37 ± 0.5° C (12 SPECIMENS)

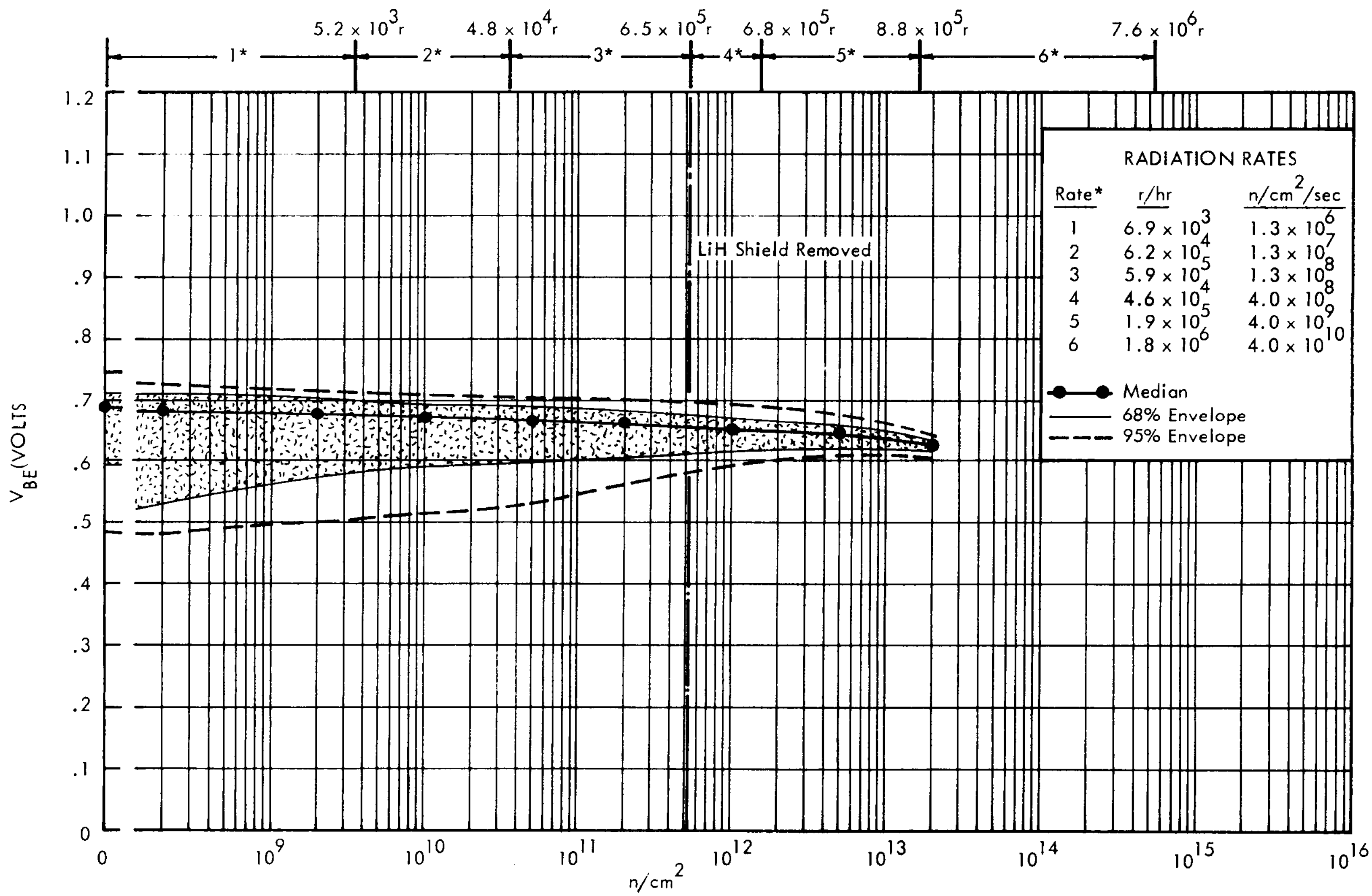

FIGURE 30 2N2222, V_{BE} (I_B CONSTANT, MEAN I_C = 20 ma) VERSUS INTEGRATED NEUTRON FLUX AT T = 37 ± 0.5° C (13 SPECIMENS)

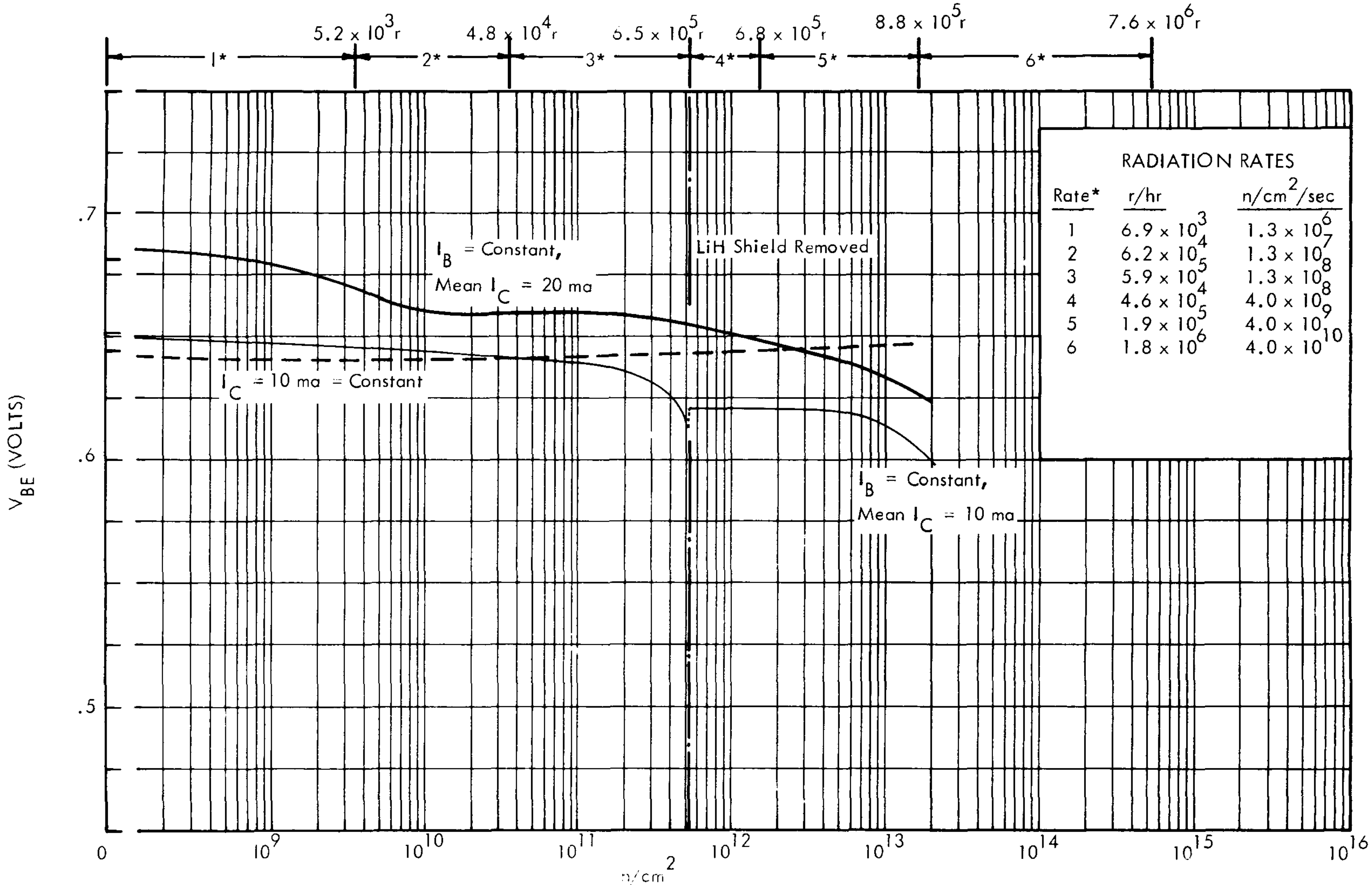

FIGURE 31 2N2222, MEDIAN V_{BE} VERSUS INTEGRATED NEUTRON FLUX AT T 37 $\pm$ 0.5° C

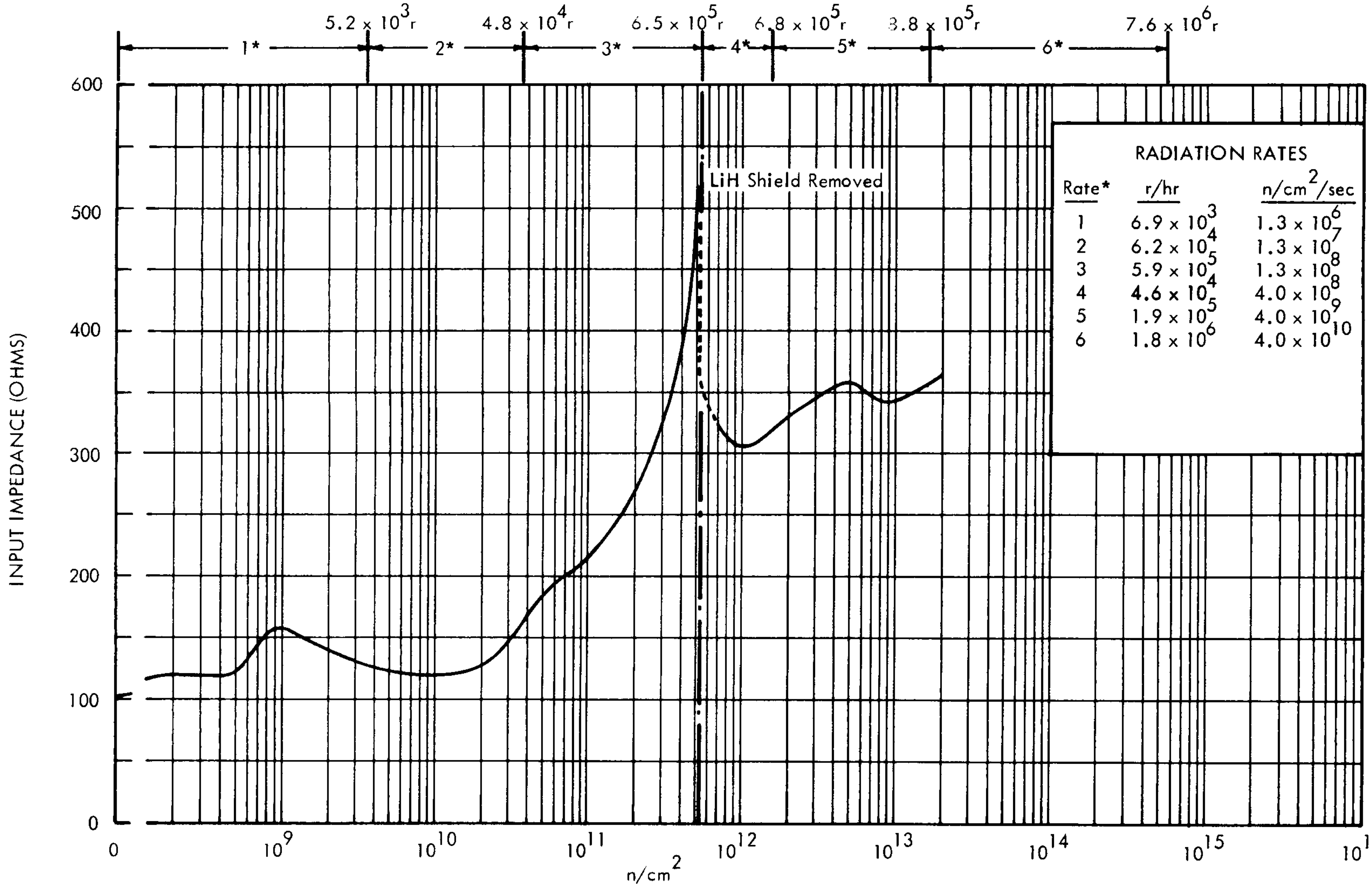

FIGURE 32 2N2222, INPUT IMPEDANCE VERSUS INTEGRATED NEUTRON FLUX AT T = 37 $\pm$ 0.5° C

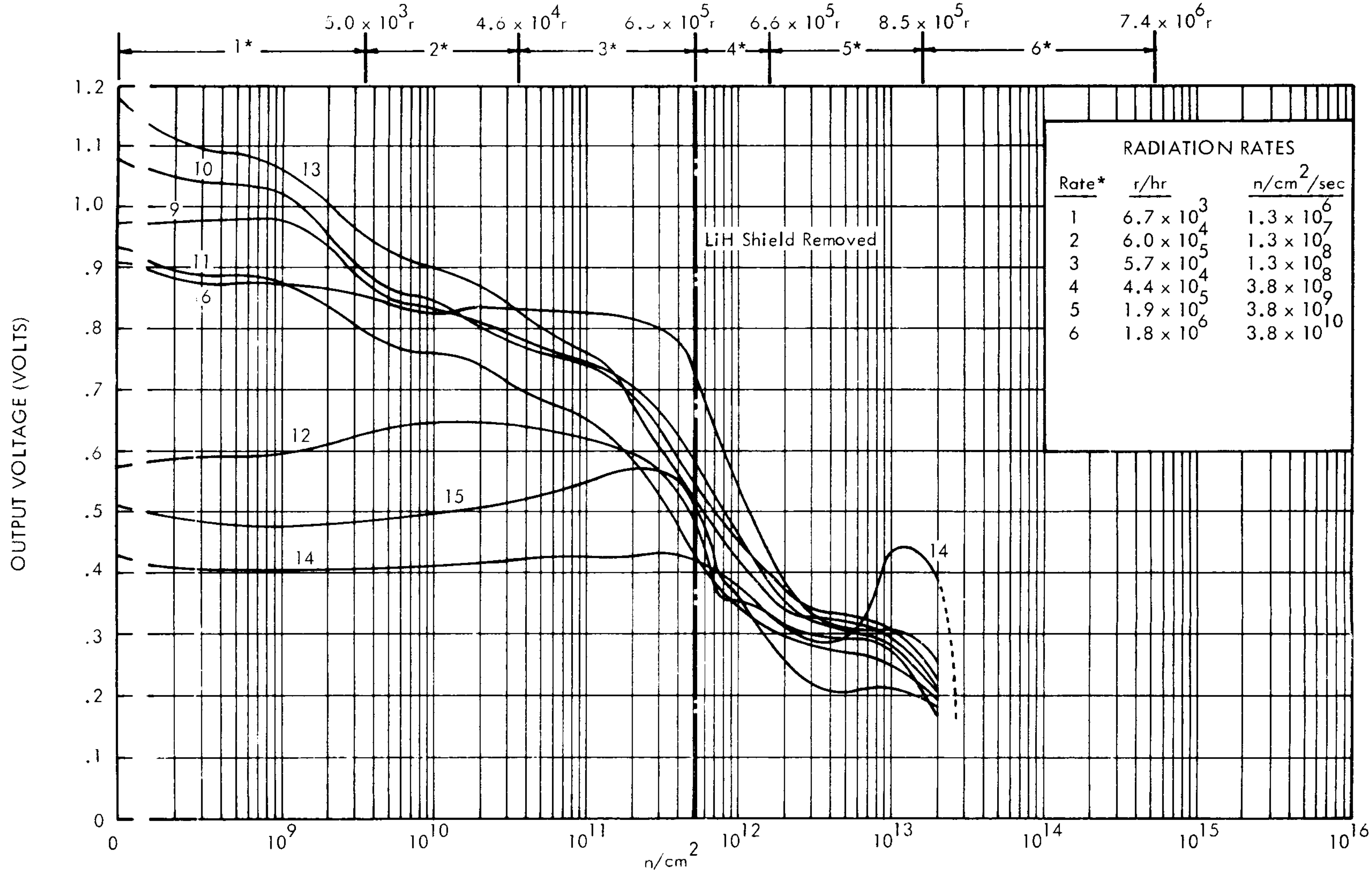

FIGURE 33 SN522, (V_{in} PIN 9, PIN 10 GROUNDED), OUTPUT VOLTAGE VERSUS INTEGRATED NEUTRON FLUX AT T = 37 $\pm$ 0.5° C

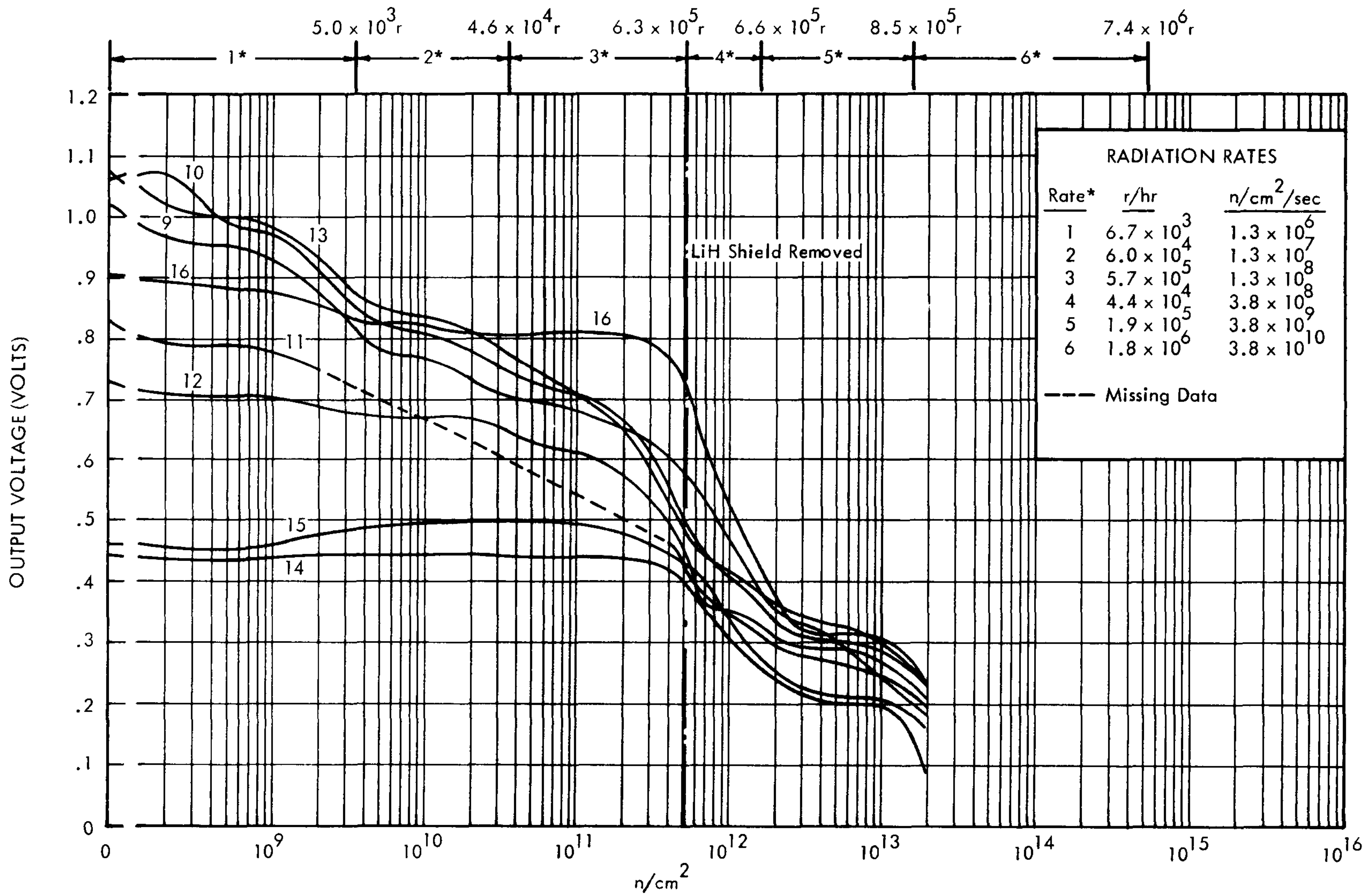

FIGURE 34 SN522, (V_{in} PIN 10, PIN 9 GROUNDED), OUTPUT VOLTAGE VERSUS INTEGRATED NEUTRON FLUX AT T = 37 $\pm$ 0.5° C

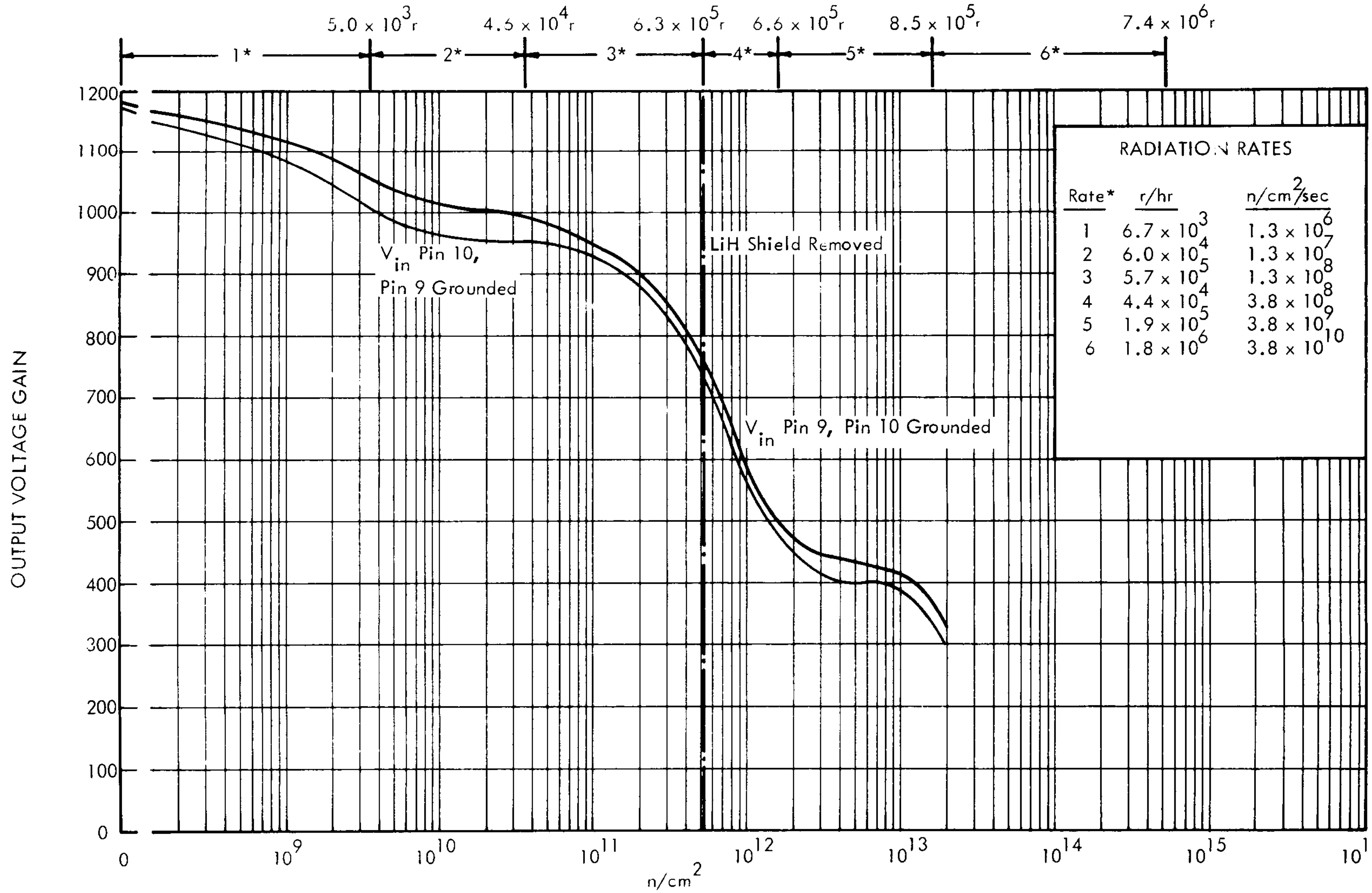

FIGURE 35 SN522 MEAN OUTPUT VOLTAGE GAIN VERSUS INTEGRATED NEUTRON FLUX AT T 37 $\pm$ 0.5° C (8 SPECIMENS)

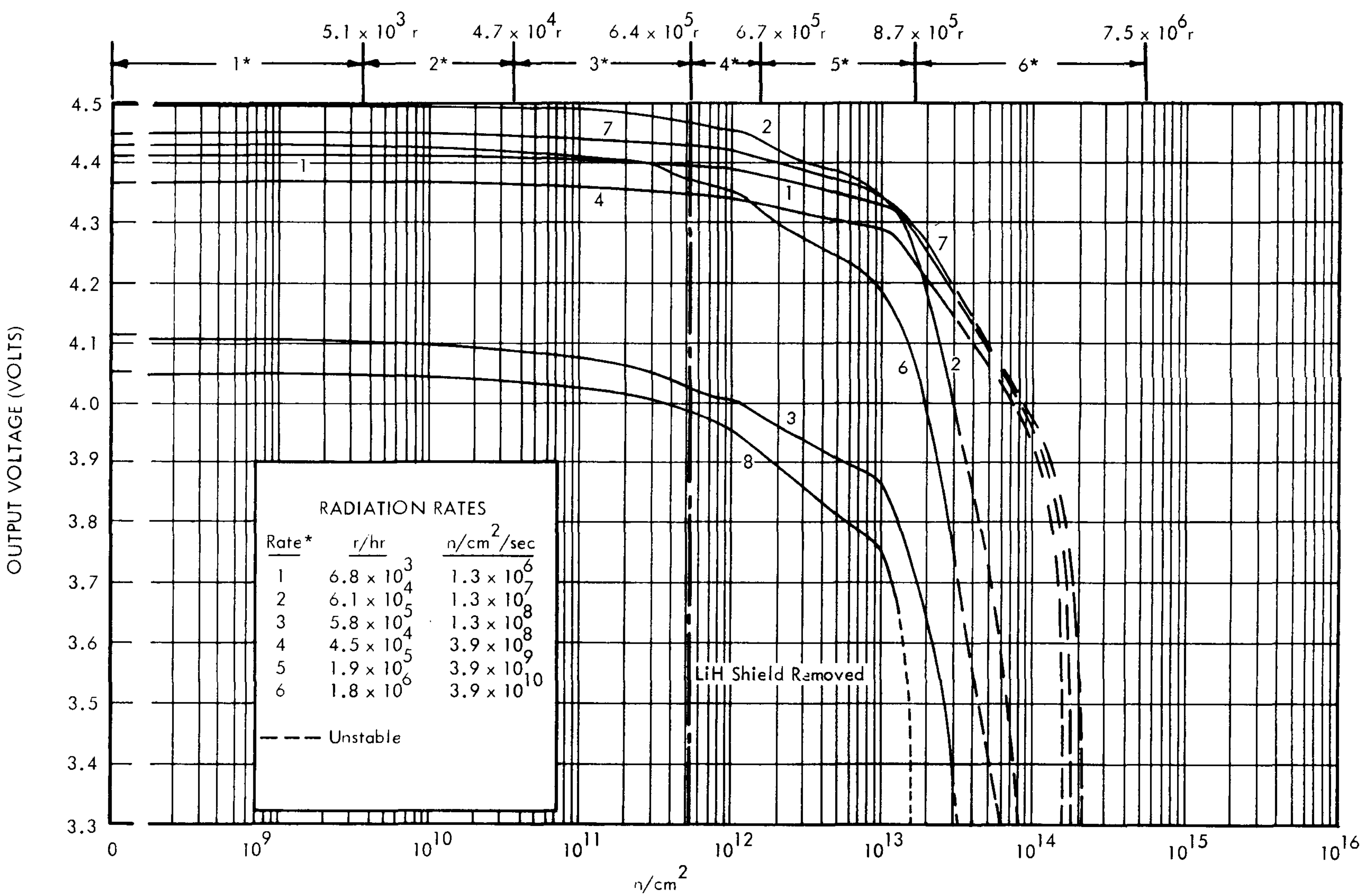

FIGURE 36 SN511, PIN 8 OUTPUT VOLTAGE (OFF, WITH LOAD) VERSUS INTEGRATED NEUTRON FLUX AT T = 37 $\pm$ 0.5° C

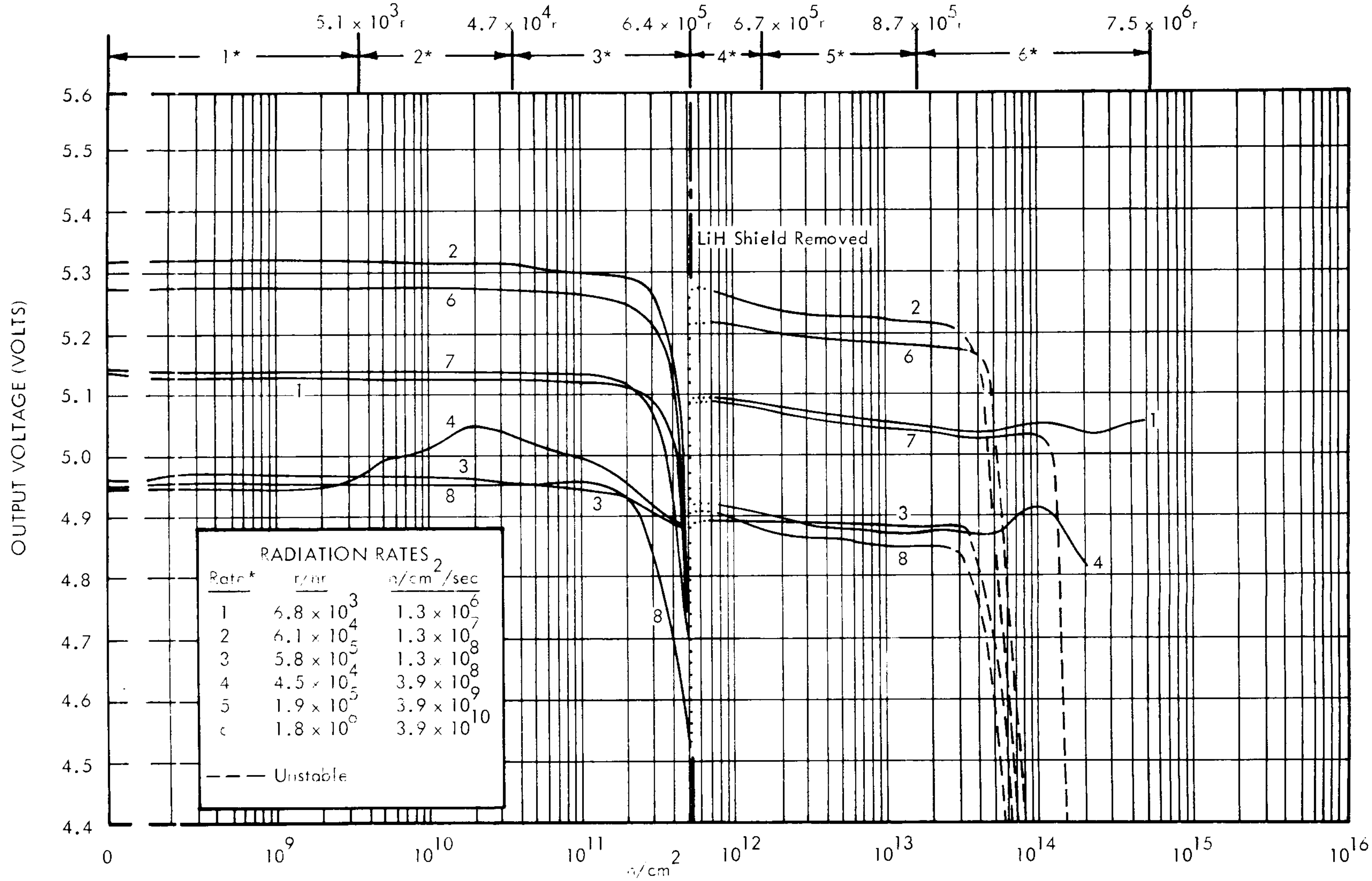

FIGURE SN-11, PIN 8 OUTPUT VOLTAGE (OFF, WITHOUT LOAD) VERSUS INTEGRATED NEUTRON FLUX AT T 37 ± 0.5° C

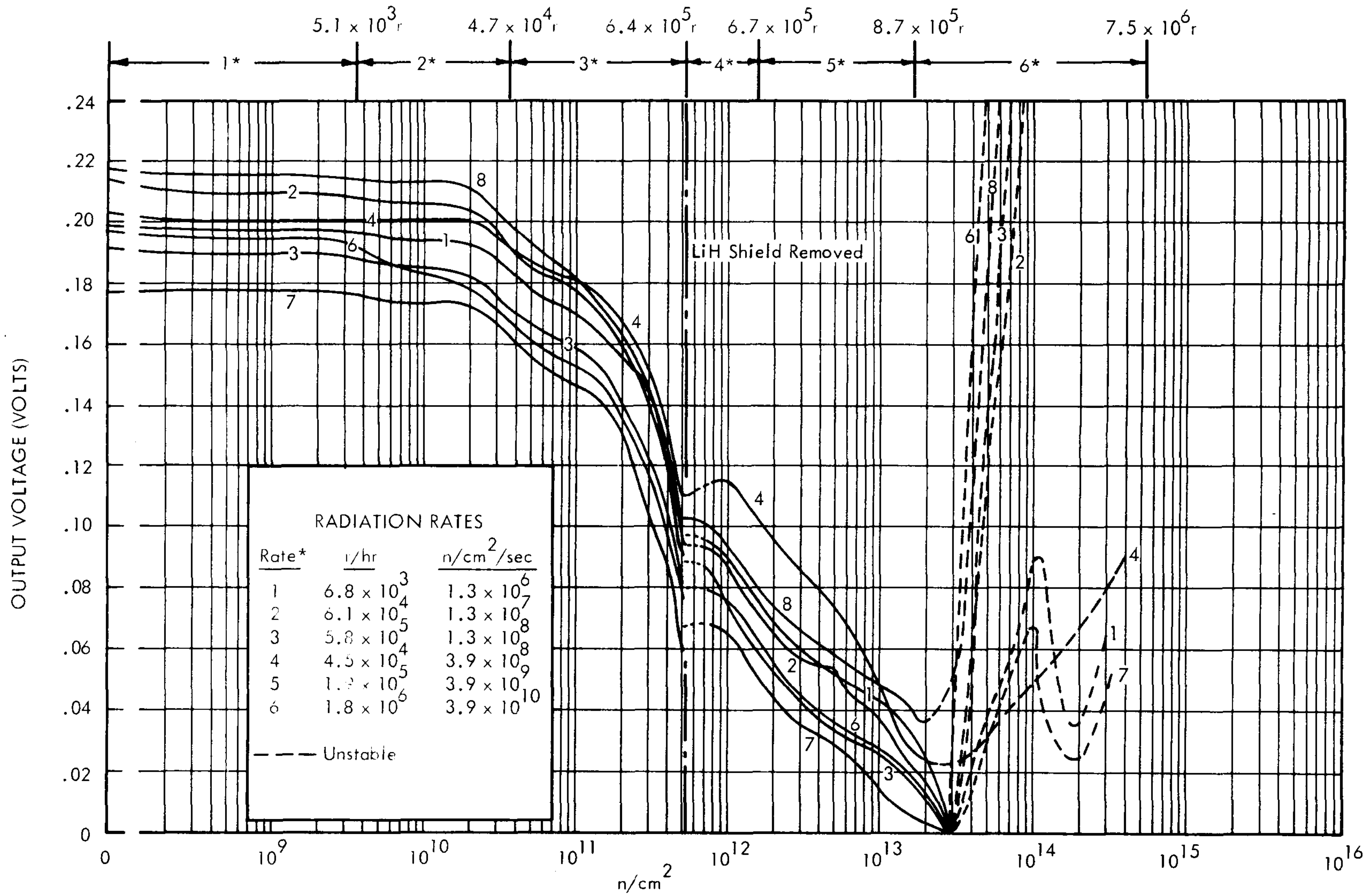

FIGURE 38 SN511, PIN 8 OUTPUT VOLTAGE (ON, WITH LOAD) VERSUS INTEGRATED NEUTRON FLUX AT T = 37 ± 0.5° C

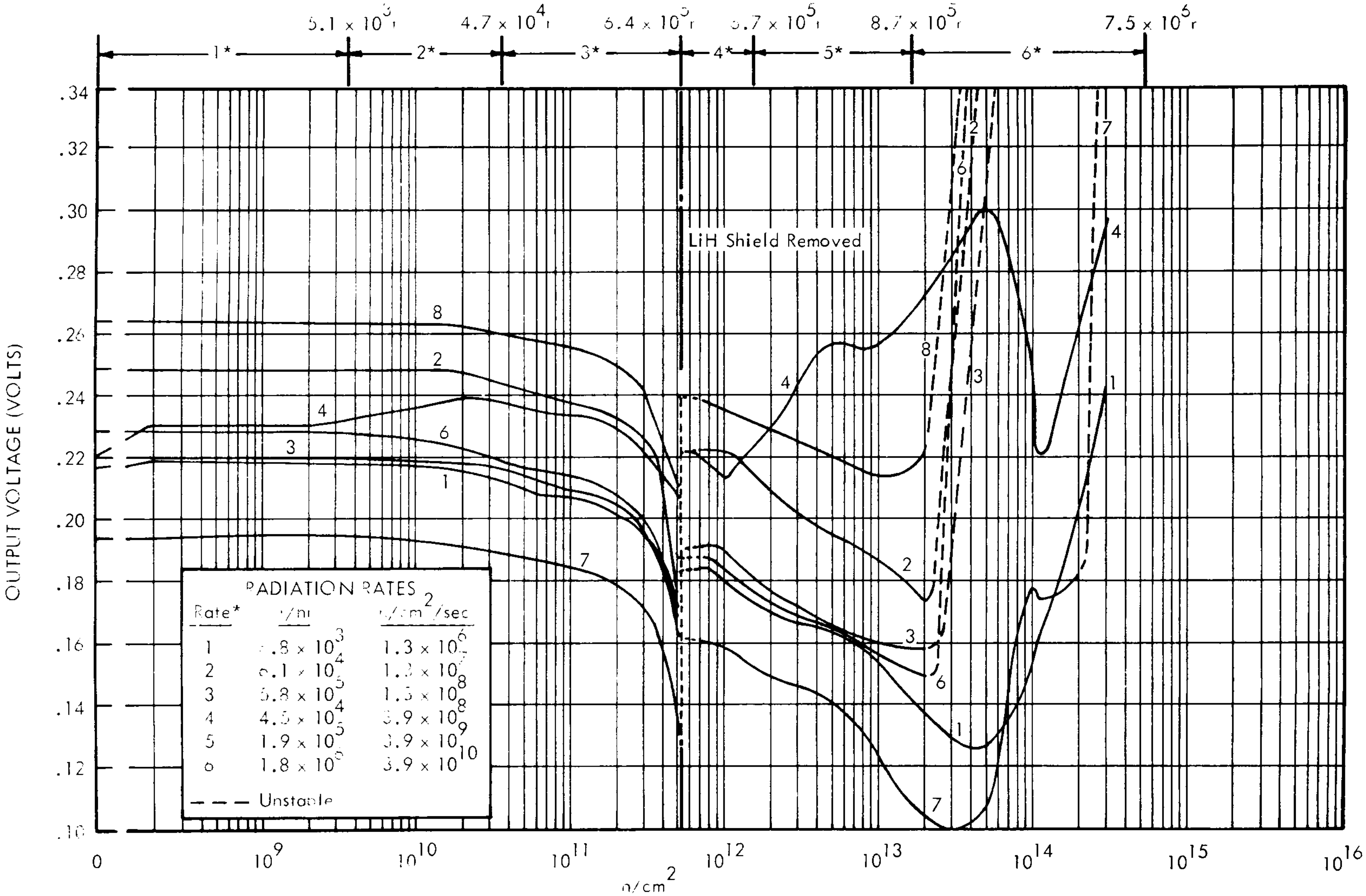

FIGURE 39 SN511, PIN 8 OUTPUT VOLTAGE (ON, WITHOUT LOAD) VERSUS INTEGRATED NEUTRON FLUX AT T = 37 ± 0.5° C

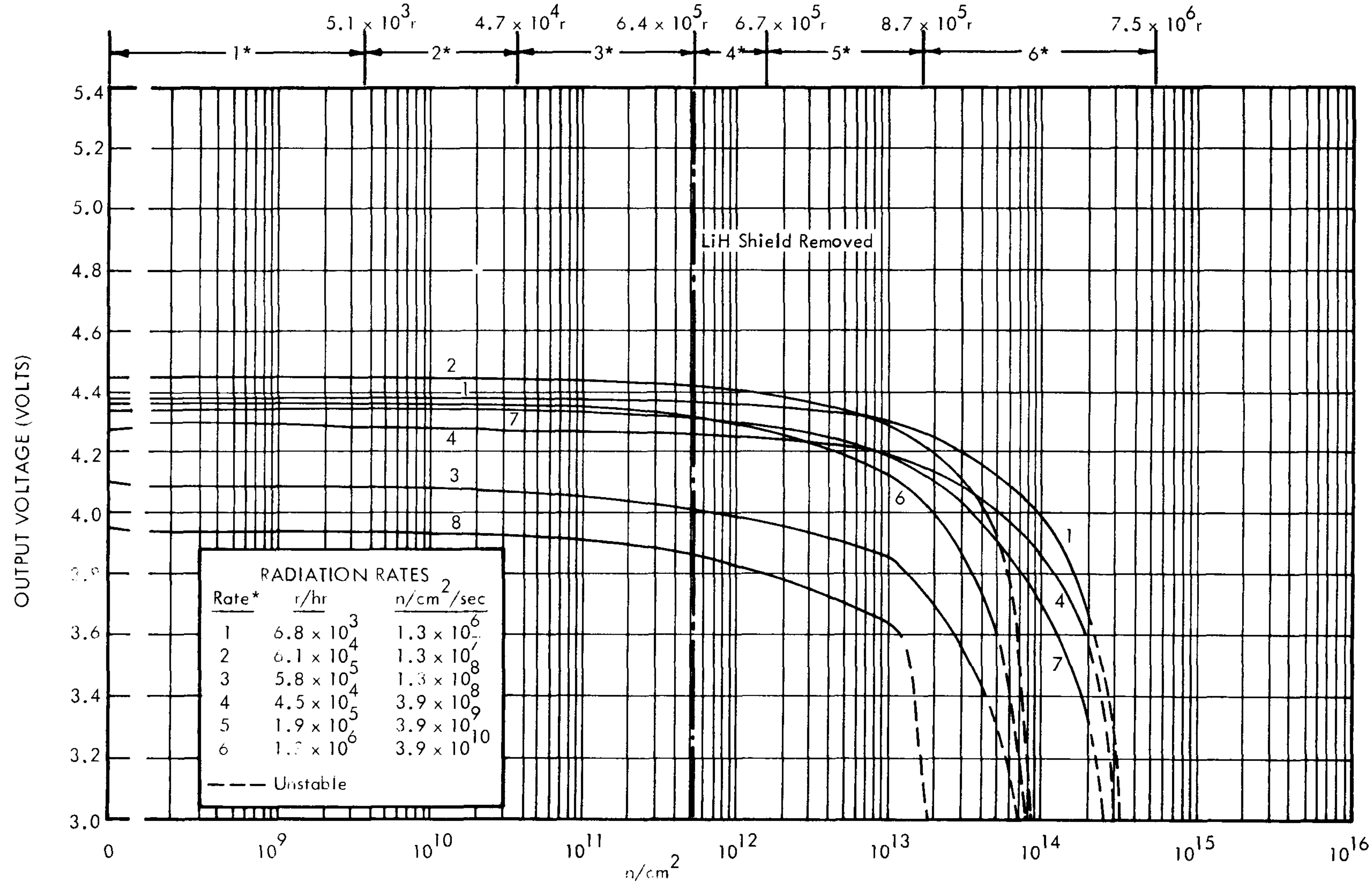

FIGURE 40 SN511, PIN 9 OUTPUT VOLTAGE (OFF, WITH LOAD) VERSUS INTEGRATED NEUTRON FLUX AT T = 37 $\pm$ 0.5° C

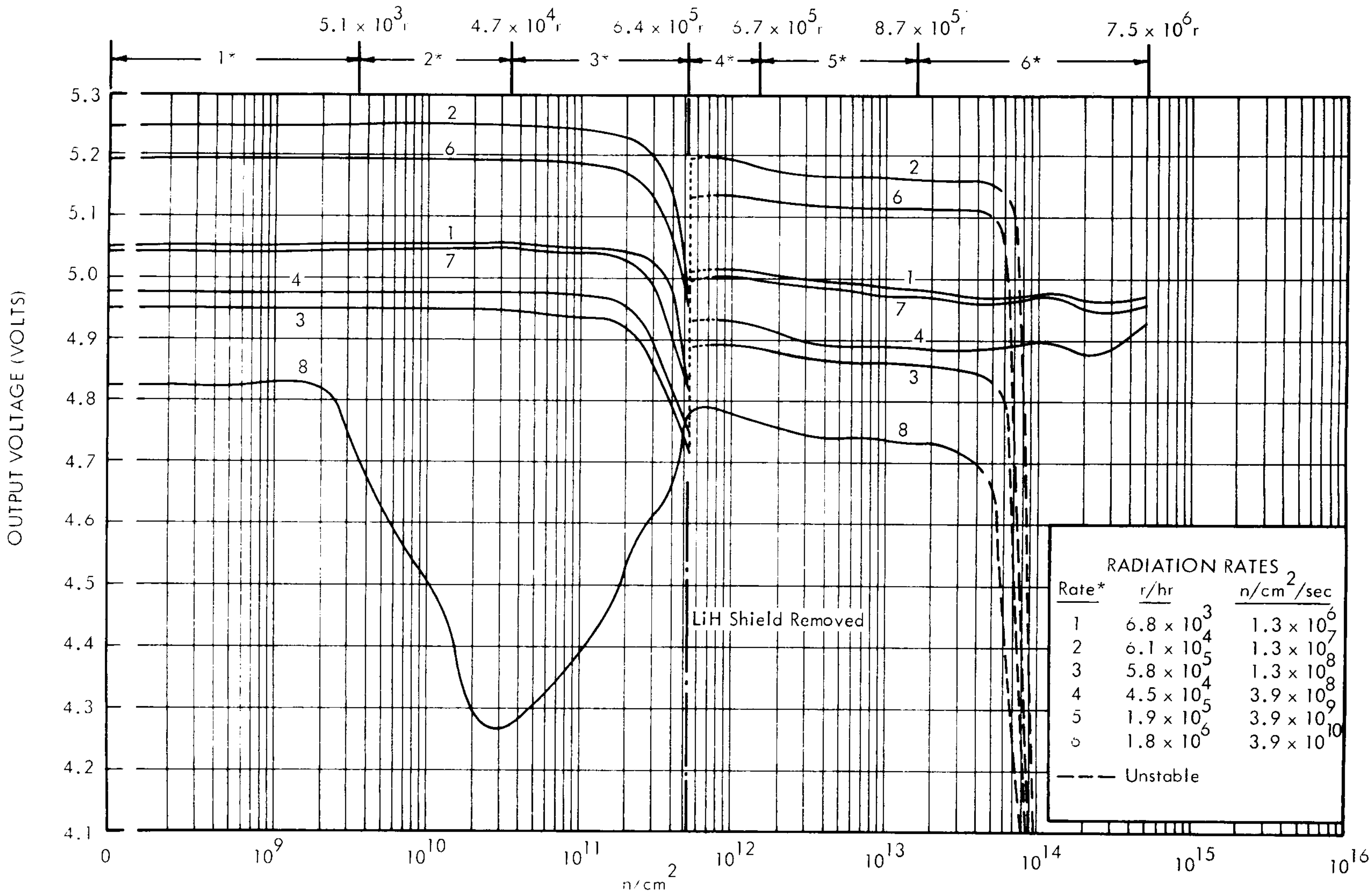

FIGURE 41 SN511, PIN 9 OUTPUT VOLTAGE (OFF, WITHOUT LOAD) VERSUS INTEGRATED NEUTRON FLUX AT T 37 ± 0.5° C

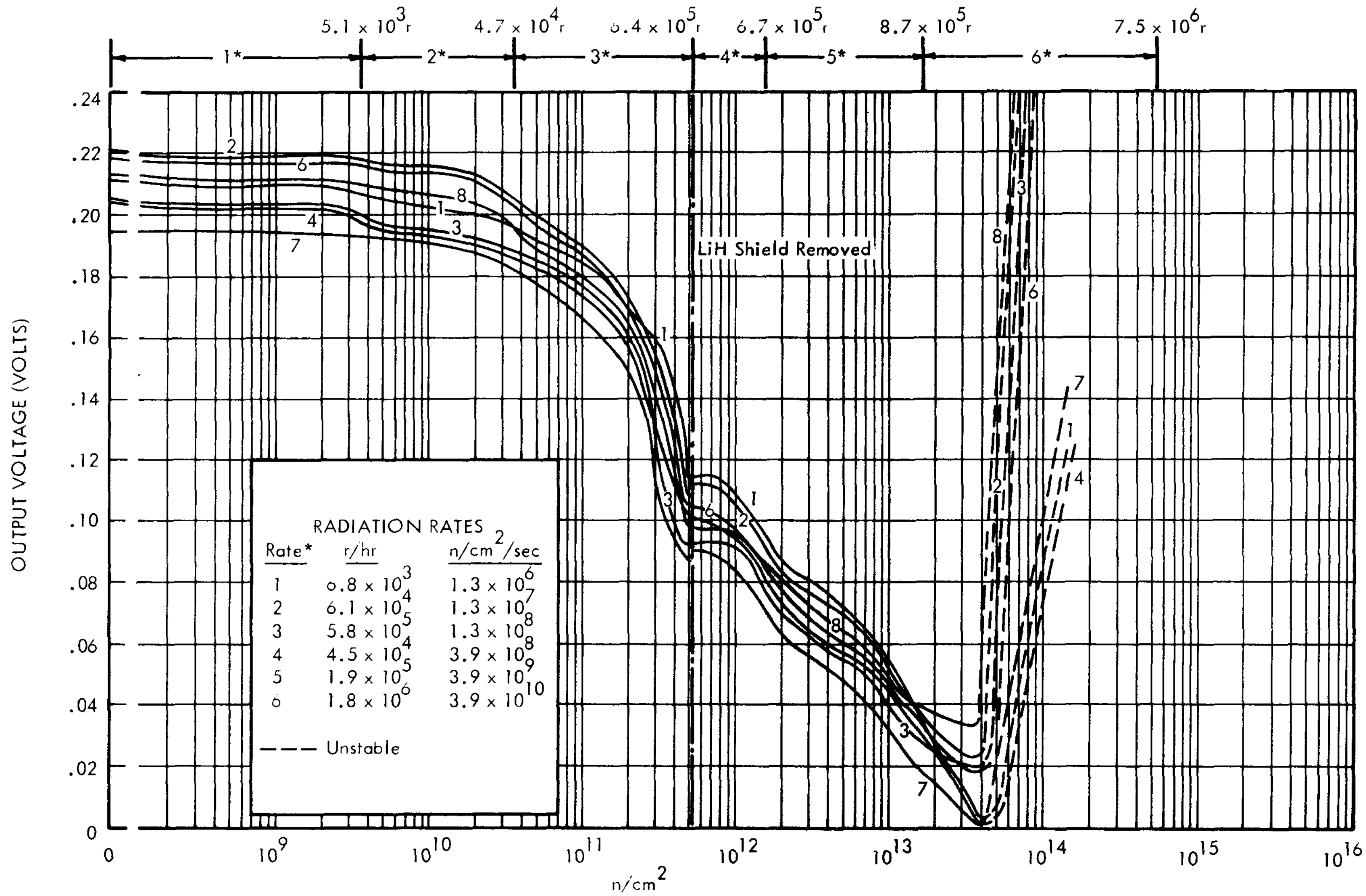

FIGURE 42 SN511, PIN 9 OUTPUT VOLTAGE (ON, WITH LOAD) VERSUS INTEGRATED NEUTRON FLUX AT T = 37 $\pm$ 0.5° C

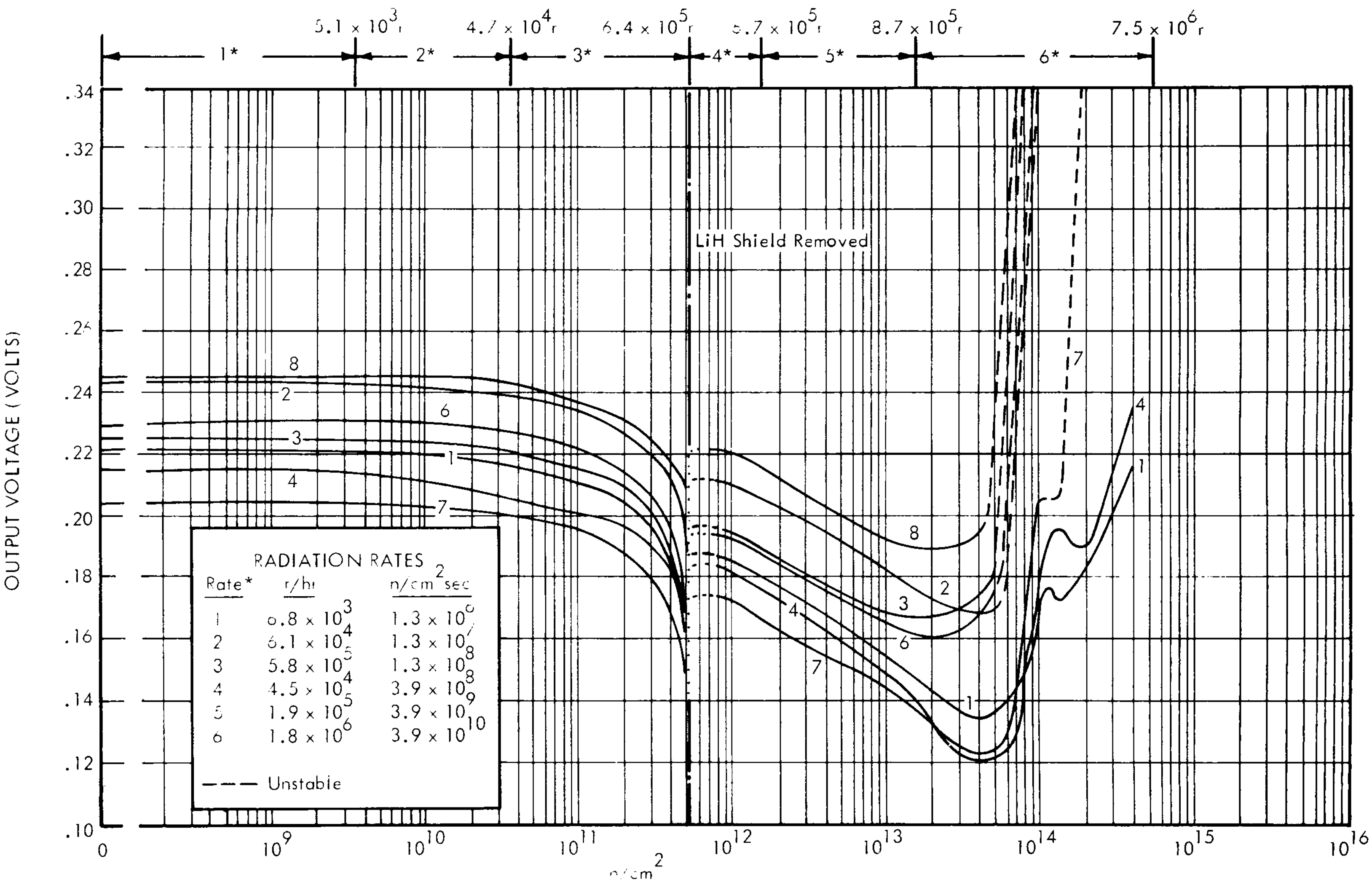

FIGURE 43 SN511, PIN 9 OUTPUT VOLTAGE (ON, WITHOUT LOAD) VERSUS INTEGRATED NEUTRON FLUX AT T 37 ± 0.°5 C

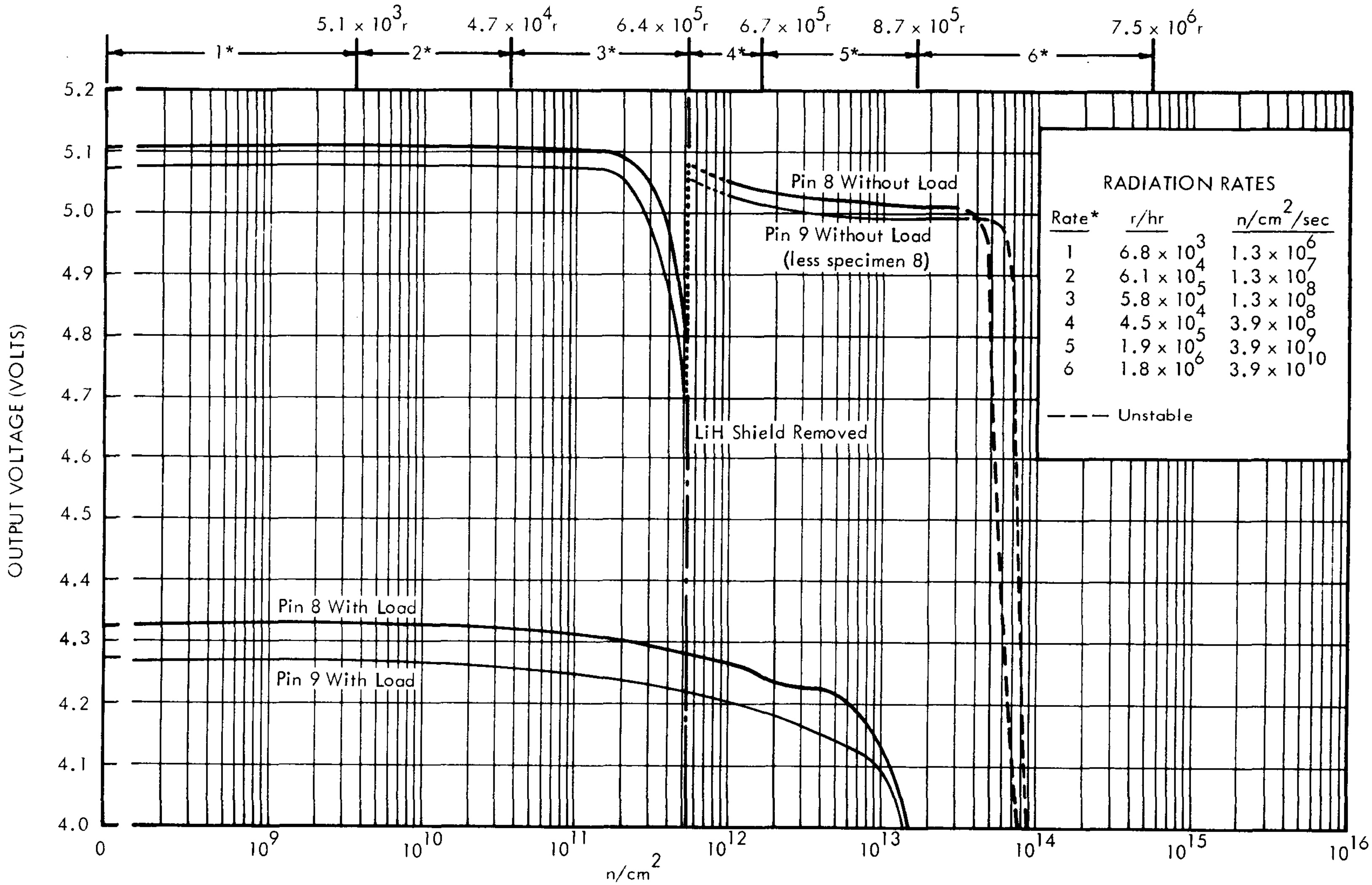

FIGURE 44 SN511, MEAN OUTPUT VOLTAGES ("OFF" POSITION) VERSUS INTEGRATED NEUTRON FLUX AT T = 37 $\pm$ 0.5° C

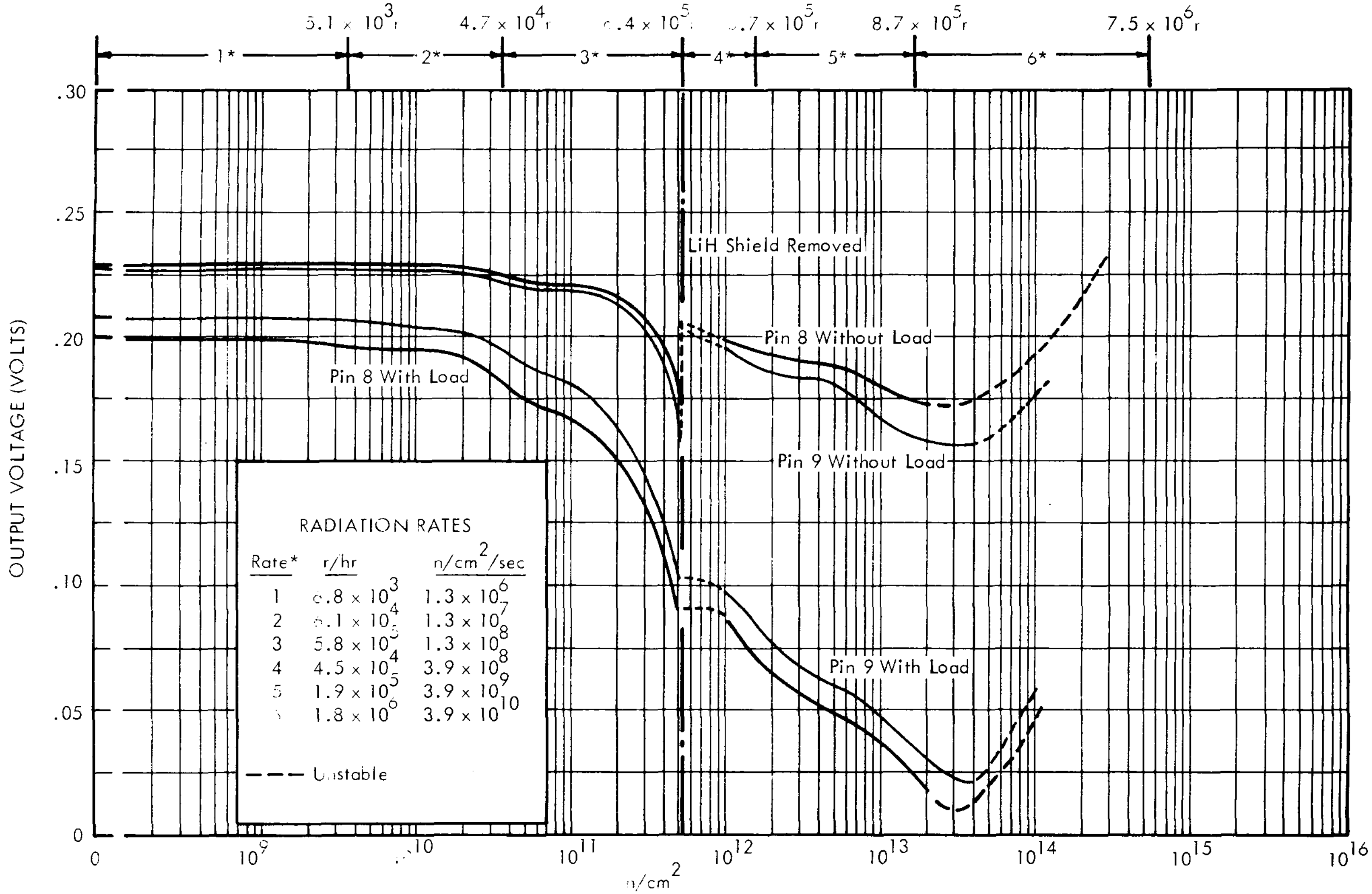

FIGURE 45 SN511, MEAN OUTPUT VOLTAGES ("ON" POSITION) VERSUS INTEGRATED NEUTRON FLUX AT T = 37 ± 0.5° C